An investigation into associations between lower extremity comfort, injury and performance in elite footballers

Submitted by

Michael A. Kinchington

Dip. Pod., Grad Dip Ex & Sports Sc; Ms Ex & Sports Science (Res); FAAPSM; FSMA

School of Sport and Exercise Science,

Faculty of Arts, Education and Human Development

April 2011

A thesis submitted in fulfilment of the requirements for the degree

Doctor of Philosophy

Supervisor: Dr Kevin Ball

School of Sport and Exercise Science,

Institute of Sport, Exercise and Active Living

Faculty of Arts, Education and Human Development

Victoria University, Melbourne, Australia

Associate Supervisor: Professor Geraldine Naughton

The Centre of Physical Activity Across the Lifespan (COPAAL), Australian Catholic University, Fitzroy, Melbourne, Australia

ABSTRACT

Background: Lower extremity injuries in running based team sports are extensive and debilitating. No studies to date have examined the contribution of lower limb comfort in preventing and or managing injuries.

Objectives: Address one of the most common issues in professional football; the high incidence of lower extremity injury by examining the relation between lower limb comfort, injury and performance.

Methods and Results: The thesis comprised six separate studies involving professional footballers from three codes of football (Australian Rules, Rugby League and Rugby Union). A novel instrument, the Lower Limb Comfort Index (LLCI) was developed to enable a technique to measure lower extremity comfort in professional football. The LLCI demonstrated good responsiveness among the football fraternity to suitability (McNemars test, P=0.019) and ease of use (McNemars test, P<0.01). The LLCI was a reliable measure of lower extremity comfort in two professional football environments; training week (ICC 0.99) and match day (ICC 0.97). Lower extremity comfort was responsive to passage of time and demonstrated high criterion-related validity for the relationship between comfort and injury. Poor lower limb comfort was highly correlated to injury (R^2 =0.77).

Footwear intervention studies were applied to a sub-group to test the effects of footwear on comfort. Tailored footwear programs resulted in reduced lower limb injury (P=0.005) and better lower extremity comfort ratings (P<0.001). Individual football rated performance measures were compared with lower extremity comfort. A footballer with poor lower extremity comfort generally did not perform well in a match situation.

Poor lower limb comfort and good match day rated performance were not well correlated (R^2 =0.25, $P=<0.001$).

Conclusion: The concept of lower limb comfort has important relevance for future use in sports medicine, research and clinical practice. High comfort scores can be interpreted as a protective mechanism for lower limb injury.

DECLARATION

"I, Michael A. Kinchington, declare that the PhD thesis entitled *An Investigation into associations between lower extremity comfort, injury and performance in elite footballers* is no more than 100,000 words in length, exclusive of tables, figures, appendices, references and footnotes. I hereby declare that this submission is my own work. This thesis contains no material that has been submitted previously, in whole or in part, for the award of any other academic degree or diploma"

Michael A. Kinchington

April 1st, 2011

ACKNOWLEDGEMENTS

I am indebted to my supervisors Dr Kevin Ball and Professor Geraldine Naughton. The following few words about them cannot do justice to their efforts, but I must make them publicly in a small attempt at thanks. Thank you to Kevin for initially accepting me under his tutelage in an area of sports medicine research to pursue paradigms not previously examined in the world of football. In doing so he placed his academic reputation on the line. Kevin Ball was akin to the football coach; ready to pounce on anything loose that may have resulted in problems for the team. In ensuring a solid game plan “the coach” encouraged my ambitions to research and was available to fine-tune the state-of-play (my thesis) when needed. When the game (research) needed tactical input, he would pull me aside at appropriate intervals (“quarter and half-time”) to provide clarity and instruction.

Geraldine Naughton, was the ever reliable rock, whom I have previously collaborated with; a premiership winning team--my Masters Degree (Sydney University 2004) in foot-shoe biomechanics. Jeri was the ever dependable midfield / on-baller who would make things happen. As all dominant players in football are capable of doing, racking up loads of contested possessions every game, week-in and week-out, she was always there to assist, guide, mentor and keep me focused on converting possessions into a score. Like our last effort, the premiership Masters Degree of 2004, she earned another Brownlow medal for this effort. I am indebted to her.

To my *de-facto* supervisors, Professor Jenny Peat, I express my gratitude for assistance, guidance, sharing of resources and wisdom. Long may our collaborations continue. To the many anonymous reviewers of the manuscripts submitted for publication, which have now either been published or are in-press, you will never know how valuable the contribution that peer-review has had to my thesis. The expression of different view-points from world leading experts provides another source of education and enabled me to view my work from different perspectives. The generally over-whelming supportive comments from the reviewers and editors, from all around the globe did two things. Firstly, it provided me with confidence that the methods adopted in the research projects were sound, which made me more enthusiastic to publish more; and secondly, enable me to clarify some of the writing, which while initially seemed clear to me, was improved by the comments of the reviewers. While the process of having papers peer-reviewed for international publication is arduous and time consuming, I would encourage others to purse this route. I believe I am a better scientist for the critique the reviewers provided.

A special mention must be reserved for my fellow colleagues in the world of football. Specifically I would like to acknowledge the assistance of Dr Matthew Cameron, Physiotherapist and Rehabilitation Coordinator; Sydney Swans football club, AFL; Dr Sharon Flahive, Team Physician; NSW Waratahs, Super 14 competition; Elizabeth Steet, Physiotherapist; Sydney Roosters, NRL; Dr John Orchard, Team Physician; Sydney Roosters, NRL; Mark Bevan, Physiotherapist; South Sydney Rugby League, NRL; and David Boyle, Head Conditioning Coach formerly at South Sydney Rugby League, NRL. Their support of the research, acknowledgement of the importance of pursuing research in football, and thus providing access to players, made data collection much easier than it would have been otherwise. To continue the theme, it would be amiss if I did not also thank the coaching and administrative staff of the football clubs who were enthusiastic and ever-supportive of the research conducted. Most importantly thank you to the players of all the football clubs who participated in the research. It was their generous involvement that made this research possible. It was their willingness to participate in the projects which has been integral to the research outcomes here-in, and in doing so they have collectively contributed to the advancement of science in football.

Like any successful footy team, support staff is critical to success. Therefore, most importantly, to my family who kept me grounded and who tolerated my 10,000 hours of academia adventure; a huge THANK YOU. This mountain conquered is in no small part due to their love and support. The most understanding of my pursuits, was my always dependable soul mate, my wife and best friend, my ever loyal companion; Maryanne. Her sacrifice, support and patience have been integral to this thesis. While at times she made noise about my many hours I was locked away in the library of our home, or the “”writing trips” I took in order to advance the preparation of this thesis, she was always accommodating and ever encouraging. This monumental feat would not have been possible without her massive efforts in keeping the home fires burning. I always knew that she was quietly proud of my (our) achievements and this was demonstrated when she would enthusiastically celebrate the success at having another of my manuscripts accepted for publication. Now that the final chapter has finally been written and proclaimed, let the party begin…

To my three children; Madeleine, Annabelle, and Xavier this achievement is just as much yours as it is anyone’s. The girls were particularly curious by their inquisitive concerns in wanting to know why I was still at school. In hindsight, the tackling of a PhD with children and family life, showed them that education and learning never ceases and results are achieved with perseverance:

*“Every day you make progress. Every step may be fruitful. Yet there will be a stretch out before you, an ever lengthening, ever ascending, ever-improving path. You know you will never get to the end of the journey. But this, so far from being discouraging, only adds to the joy and glory of the climb” (*Sir Winston Churchill; British Prime Minister, 1940-45 and 1951-55)*.*

I truly thank Madeleine, Annabelle and Xavier for their sacrifices when at times it seemed family life was a combination of work (to pay the bills) and study (to climb the mountain of knowledge). May they also pursue their dreams!

PUBLICATIONS

The following publications directly arising from this thesis in support of this thesis:

1. Kinchington, M., Ball, K., Naughton, G. (2011). Development of a novel rating system to assess lower limb comfort. Journal American Podiatric Medical Association, 101, (5), 371-384. (Thesis Chapter 3); [Refer Appendix C].

2. Kinchington, M., Ball, K., Naughton, G. (2010). Reliability of an instrument to determine lower limb comfort in professional football. Open Access Journal of Sports Medicine, Volume 2010, 1, 77-85. (Thesis Chapter 4). [Refer Appendix C].

3. Kinchington, M., Ball, K., Naughton, G. (2010). Monitoring of lower limb comfort and injury in elite football. The Journal of Sports Science and Medicine, Volume 9, Issue 4, 652-663. (Thesis Chapter 5). [Refer Appendix C].

4. Kinchington, M., Ball, K., Naughton, G. (2011). Effects of footwear on comfort and injury in professional football (Rugby League). Journal of Sports Sciences, 29, 13, 1407-1415. (Thesis Chapter 6); [Refer Appendix C].

5. Kinchington, M., Ball, K., Naughton, G. (in press). An investigation into the role of a footwear intervention program for professional footballers. an intra-club control and intervention study. Gazzetta Medica Italiana. (Thesis Chapter 7); [Refer Appendix C].

6. Kinchington, M., Ball, K., Naughton, G.(http://dx.doi.org/10.1016/j.ptsp.2011.02.001; in press). Relation between lower limb comfort and performance in elite footballers. Physical Therapy in Sport. (Thesis Chapter 8); [Refer Appendix C].

TABLE OF CONTENTS

CHAPTER TWO

Systematic Review of Lower Extremity Musculoskeletal Comfort in Football

CHAPTER THREE

Development of a Novel Rating System to Assess Lower Extremity Comfort

---

CHAPTER FOUR

Reliability of An Instrument To Determine Lower Limb Comfort in Professional Football

---

CHAPTER FIVE

Monitoring of Lower Extremity Comfort and Injury in Elite Football

---

CHAPTER SIX

Effects Of Footwear On Comfort and Injury In Professional Football

---

CHAPTER SEVEN

An Investigation Into The Role Of A Footwear Intervention Program For Professional Footballers. An Intra-Club Control and Intervention Study

---

CHAPTER EIGHT

Relation Between Lower Limb Comfort and Performance In Elite Footballers

CHAPTER NINE

Conclusions and Recommendations

CHAPTER TEN

Appendices

TABLES

FIGURES

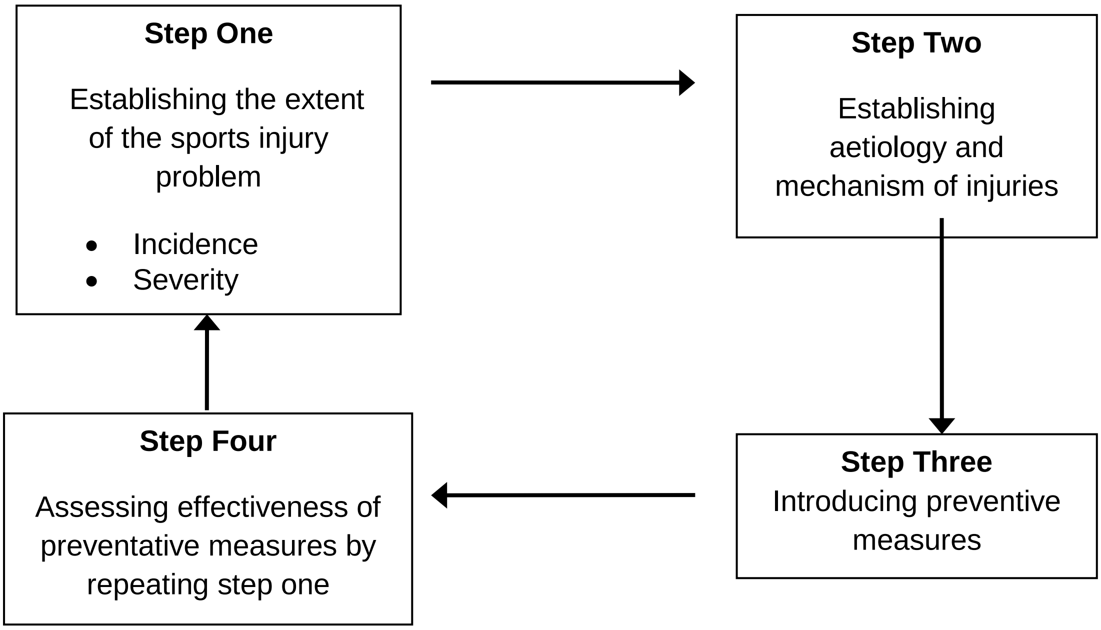
CHAPTER ONE

INTRODUCTION

1.1 INTRODUCTION

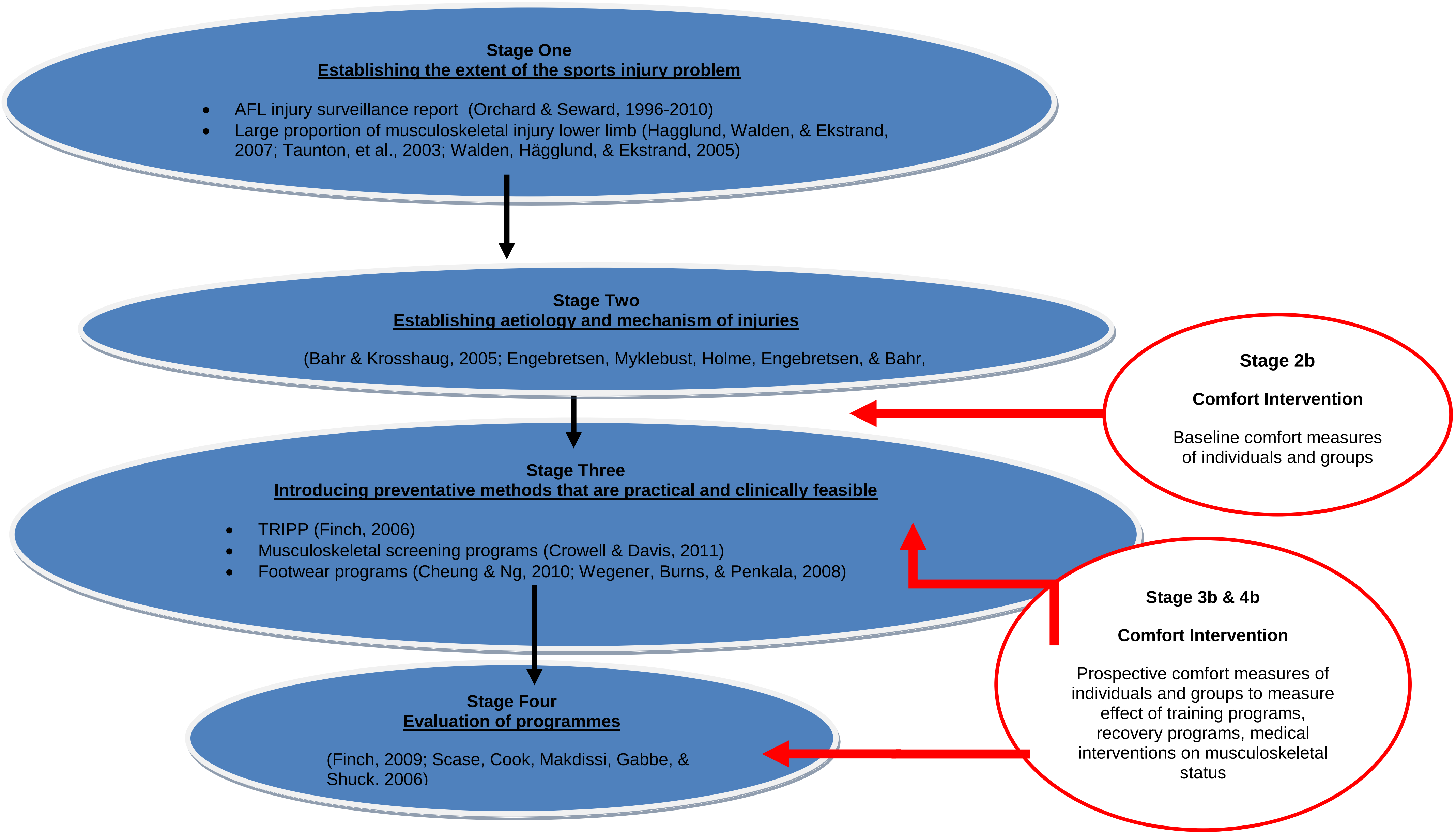
The thesis titled "*An investigation into associations between lower extremity comfort, injury and performance in elite footballers"* further explores and contributes to the sports injury-medicine paradigm first developed by van Mechelen et al (1992). The van Mechelen model (Figure 1.1) has been reinforced over the years with substantial efforts by researchers. For example, Orchard and Seward (2009), annually publish the world's largest continuous football injury surveillance data. Finch (2006) proposed the TRIPP model (Translating Research into Injury Prevention Practice) which advocates the need for prevention programs to be capable of pragmatic application and measurable outcomes in clinical settings. In addition, Bahr and Krosshaug (2005) reinforced a multifactorial approach to the assessment of all internal and external risk factors.

Figure 1.1 *van Mechelen's sequence of sports injury prevention. Modified from van Mechelen et al. (1992).*



The thesis investigates an addition to the sports injury paradigm by adding a new layer not previously researched in sports medicine literature; the role of lower extremity comfort in running-dependent football codes (Figure 1.2). The addition of a comfort layer to the van Mechelen model is postulated to enhance the theoretical components of the sports injury model by the addition of a clinical tool for health practitioners. The comfort application enables a prospective measure of the health status of the lower extremity at specified stages of the sports-injury model.

Figure 1.2 *A proposed conceptual comfort framework modified from van Mechelen et al., (1992) model providing a clinical measure of musculoskeletal well-being.*



1.2 RATIONAL & PURPOSE

Injury statistics in running-based team sports (the rugby codes, soccer, Australian rules and American football) indicate a high proportion of injuries occur to the lower limbs. Lower extremity injuries result in significant financial and social impacts (Engebretsen & Bahr, 2005). Two cost analyses indicate sports-related injuries cost the community in excess of $2 billion annually (Medibank, 2006; Orchard & Finch, 2002). These injuries result in significant financial and social impacts to players, clubs and organisations. Therefore, reduction of lower extremity injury is an important criterion in football for reasons ranging from performance-based criteria (player welfare, footballer fitness, team cohesion due to lack of injuries, and winning games) to financial considerations (player payments, medical rehabilitation costs, and club sponsorship based upon team success).

The relationship between lower extremity comfort and injury in professional football is a novel area of investigation. The research presented in this thesis represents the first Australian based professional football prospective study. The outcomes will provide injury minimization strategies for professional footballers and anticipated flow on contribution to amateur football and exercise enthusiasts.

1.3 OBJECTIVES AND HYPOTHESES OF THE STUDY

The general objective of the thesis was to:

Demonstrate an improved understanding of the role of comfort with injury and perceived performance in professional football. This involved specific objectives of:

I. The development of an instrument to measure lower extremity comfort (Lower Limb Comfort Index).
II. Applying the Lower Limb Comfort Index (LLCI) in the field of professional football competition with 182 professional footballers encompassing three football codes (Australian Football, Rugby league and Rugby union).
III. Comparing the effects of a tailored footwear program in two different groups of Rugby league players to assess the effect of footwear on comfort and injury.
IV. Examining associations between lower extremity comfort and perceived performance.

The hypotheses tested were:

I. The LLCI is a reliable tool to measure changes in lower extremity limb comfort over time in a competitive football environment.
II. Poor lower limb comfort is positively correlated with injury and negatively correlated with high perceived performance.

III. Aspects of a tailored footwear program are of benefit to professional footballers for comfort and injury outcome measures.

1.4 THE TOPIC/ QUESTION / PROBLEM IDENTIFIED

The context of the thesis is described via a systematic review of literature (Chapter 2), which provides a rationale for the study to be performed. The thesis progresses in a logical sequence, of six related studies. The studies commence with the development of an instrument to measure lower extremity comfort (Chapter 3); establishing the reliability of the LLCI (Chapter 4); the application of the lower extremity measure for comfort and injury in football (Chapter 5); two control and intervention studies monitoring the effect of footwear on comfort and injury within rugby league (Chapters 6 and 7); and finally exploring whether comfort is associated with performance (Chapter 8). All of the studies are supported by publications directly arising from this thesis (page VIII). The final chapter (Chapter 9) contains a summary of the research findings and a number of conclusions and directions for further study are discussed.

1.5 DELIMITATIONS TO THE STUDY

The experimental design of the study was delimited to a number of factors.

I. Professional footballers playing senior and reserve grade football from the dominant winter football codes played in Australia were selected as the targeted population for the study. Football (soccer) was not included as it is played in summer in Australia and data collection for other codes was more conveniently collected within the same time frame. The design of the study was not able to accommodate soccer, but it is speculated the results from the three codes studied would be applicable to football (soccer).

II. This study was delimited to lower limb comfort indices. Variables did not include lower extremity morphology and biomechanics of individuals because the primary objective was centred on comfort. More specifically, lower extremity comfort provided a simple end-point measure and was considered the culmination of the interplay of multiple variables which in research are difficult to control.

III. Other variables such as environmental conditions (playing surfaces), rate of perceived exertion, movement patterns (distances covered) per player/game were not measured. These factors will affect musculoskeletal loads. It was considered that where ground surfaces or where footballers had high exertion rates, musculoskeletal fatigue would be captured by a low comfort score.

1.6 LIMITATIONS

I. The speed of matches was not within the control of the research but usual loading was considered necessary for testing the feasibility of the lower limb comfort index.

II. Other limitations included player motivation that may have wavered during the course of data collection, which occurred for up to 30 weeks of a football season. Therefore, motivation may influence some data.

III. Although, the comfort results were confidential and not discussed with coaching staff, it is acknowledged players may have inflated individual comfort scores, in an effort to conceal an ailment. Some athletes may not have shared the same priority for honesty in responses as others, but this was not possible to assess.

IV. The conditions under which players competed and trained were likely to vary across the season, but climatic control was beyond the scope of the study.

V. Other limitations were measures of individual football form, nutrition, and general well-being; all of which were outside the scope of the research.

1.7 SIGNIFICANCE OF STUDY

Lower limb injuries are associated with a large number of intrinsic and extrinsic factors that affect musculoskeletal load and tolerance (Bahr & Krosshaug, 2005). The past two decades of sports medicine literature provides consensus that not one, isolated risk factor dominates the lower limb injury paradigm and no one intervention is a panacea for management of injury. Rather, injury causes and intervention strategies are multi-factorial, complicated, and require constant appraisal and revision (Van Mechelen, Hlobil, & Kemper, 1992).

The chapters in this thesis are the first to profile physical well-being of the lower extremity of footballers contracted to three codes of professional football played in Australia (Australian Football League, National Rugby League, and Super 14 Rugby Union). The method of determining the health status of the lower extremity of professional footballers and the effect of lower extremity physical well-being on injury involved the development of a lower extremity comfort index. The clinical application of comfort theory as a component of injury management lies in the use of a self-rating psycho – physical comfort index. The setting of individual lower limb comfort benchmarks in sport for players can be used to monitor lower limb musculoskeletal health, plan for training and formulate prehabilitation and rehabilitation programs. If discomfort can be identified early, it may be possible to intervene before injuries deteriorate.

The study outcomes have clinical relevance to health professionals who treat injury, provide comfort and injury data for stakeholders of athletic footwear, may contribute to footwear design for the benefit of the consumer, and enhance the scientific community's understanding of lower limb injury in professional football codes.

CHAPTER TWO

SYSTEMATIC REVIEW OF LOWER EXTREMITY MUSCULOSKELETAL COMFORT IN FOOTBALL

2.1 ABSTRACT

Background: Comfort concepts for musculoskeletal disorders and clinical practice are well documented in the domains of medicine and nursing. Research involving footwear comfort suggests that lower extremity musculoskeletal physical comfort also has a role within sports medicine. However, this concept is under represented and is a concept not previously investigated within professional football. It is postulated that an ecological association between physical comfort and football performance exists.

Objectives: To identify whether measures of physical comfort have been utilized in professional football as a barometer of lower extremity physical well-being.

Methods: The data bases CINAHL, PsycINFO, Medline, SPORTDiscus, Cochrane, and Scopus were searched to retrieve all peer-reviewed publications. Articles were categorized according to the relevance of research to lower extremity comfort especially applicable to football. When comfort themes were lacking, the search was expanded to include physical activity. Because of limited available literature for football and comfort, an expansion to the descriptive terms of lower extremity pain and discomfort was deemed acceptable for relevance to the selected topic.

Results: The search retrieved 2117 publications, with exclusions of publications before 1990. Forty-six percent (N=976) of publications established comfort themes specific to the lower extremity. Less than 5% (N=46) of comfort-related themes were relevant to physical activity and or, sport. None of the publications examined relationships between comfort and lower extremity injury specific to football. In contrast, pain measures applicable to the lower extremity were more commonly cited (54%, N=1141). Of these, 211 (18%) publications were directly associated with physical activity, however less than 3% specifically related to football.

Conclusions: The area of lower extremity comfort is under-researched and is a concept not previously investigated within professional football. Pain is a theme more commonly cited in football injury literature. The relevance of comfort to running based activities provides impetus to investigate comfort concepts within football of all codes. The research represents an exciting opportunity to contribute to the early detection of sports injury.

2.2 INTRODUCTION

Musculoskeletal disorders within the confines of general society, are postulated to have significant detrimental effects for functional independence, and place a burden upon society (Handoll, Gillespie, Gillespie, & Madhok, 2007). Similarly, pain and discomfort in sport can compromise performances of individuals, have long term health consequences, and interrupt sporting careers (Gabbe, Finch, Wajswelner, & Bennell, 2004). The sports medicine literature documents multiple examples of postulated causative risk factors for injury, pain and disability. While intrinsic physical and extrinsic environmental factors are acknowledged as potentially injurious triggers, the role of individual musculoskeletal physical comfort may also be important to the sports injury paradigm.

Fundamentally, comfort is a subjective response drawn from past experiences influenced by physical, mechanical, psychological and neurophysiological factors. The term can signify both a physical and mental phenomena (Kolcaba & Kolcaba, 1991). In the context of musculoskeletal pain-dysfunction, physical comfort is the relief from discomfort. Comfort as a measure is also difficult to standardise, because comfort cannot be directly measured (Slater, 1985) due to inter-individual variability in perceptions.

Comfort concepts for musculoskeletal disorders and clinical practice are well documented (Kolcaba & Steiner, 2000), but it is proposed that physical comfort also has a role within sports medicine. It is postulated that an ecological association between physical comfort and football performance exists. For example, if an individual experiences lower extremity discomfort, then comfort is impaired and physical activity will subsequently be compromised. Existing literature has attempted to highlight how comfort has beneficial outcomes in workplace environments such as military services (Mundermann, Stefanyshyn, & Nigg, 2001), manufacturing industries (Orlando & King, 2004), and nursing (Chiu & Wang, 2007).

Positive comfort effects have been postulated with footwear conditions that alter muscle function (Miller, Nigg, Liu, Stefanyshyn, & Nurse, 2000; Mundermann, Nigg, Humble, & Stefanyshyn, 2003b; Mundermann, Nigg, Stefanyshyn, & Humble, 2002), and physiological responses as well as reduce load forces (Che, Nigg, & De Koning, 1994; Hong, Lee, Chen, Pei, & Wu, 2005). It has been speculated that good posture promotes whole body comfort (Witana, Goonetilleke, Xiong, & Au, 2009), that comfort is affected by plantar foot pressure, foot sensitivity and foot-leg alignment (Che, et al., 1994; Nigg, Nurse, & Stefanyshyn, 1999) and is related to fatigue and performance (Nigg, 2001; Nigg, et al., 1999). These areas of research are also applicable to football, because the demands upon the musculoskeletal system are constantly challenged and in elite competition, individuals will not cope without appropriate physical conditioning (Junge, Dvorak, Chomiak, Peterson, & Graf-Baumann, 2000) which will affect comfort.

2.3 METHODS

The purpose of this systematic review of literature was to identify whether comfort as a concept has been utilised in professional sport generally and in the football codes more specifically. Because the terms comfort, discomfort and pain are interchangeably used to portray a state of physical wellbeing, the three terms were searched.

2.3.1 Data source

The online data bases CINAHL, PsycINFO, Medline, SPORTDiscus, Cochrane, and Scopus were searched to retrieve all available publications related to lower extremity comfort or pain measures in professional football for the period January 1990 to December 2010. All data bases were systematically searched using the same keywords and text words and where relevant, smart word searching was used when the data bases did not recognise the search words. Peer-reviewed journal publications with themes exploring any facet of self-rated comfort and pain measures associated with the lower extremity were extracted. The term lower limb was used interchangeably with lower extremity, lower leg and limb. The region included the anatomical areas of the feet, ankle, calf and / or Achilles, shin, knee and shoes and / or footwear, and / or football boots. Table 2.1 outlines the specific search terms that involved six search levels.

Lower extremity comfort was interpreted in its broadest context and included public health–related publications concerning comfort and work place literature associated with the lower extremity. Primary exclusion criteria incorporated publications derived from the works contained within this thesis (Page VIII), non-peer reviewed publications, topics more than 20 years old, case studies, paediatric, amputee, broad surgical and anaesthesia themes and non human information.

Secondary exclusions (Table 2.1) involved (i) self-rated measures of comfort or pain which with closer scrutiny had surgical themes as the primary focus; (ii) duplicate publications and non-relevant anatomical areas of the lower extremity such as the groin, hamstrings, buttock and hip. All remaining titles, keywords, and abstracts were scrutinized and further publications were excluded if considered irrelevant to football or physical activity.

In addition to scrutinizing the content of publications deemed relevant, the references of each publication were reviewed in a manual search. If references were identified as potentially meeting search criteria, they were cross referenced against publications selected from the original search to ensure no relevant publications were missed.

2.4 RESULTS

A systematic review of literature resulted in no comfort studies associated with the lower extremity in football. The current studies derived from literature in the realms of professional sport overwhelmingly investigate injury risk, epidemiology, physiological parameters and psychological effects of football upon individuals, but these themes were outside the scope of our search strategy.

2.4.1 General search

Table 2.1 illustrates the results of the search strategy. We retrieved a total of 2117 titles from CINAHL (N=382), PsycINFO (N=147), Medline (N=171), SPORT Discus (N=416), and Scopus (N=1001). The Cochrane database did not result in any meta-analyses previously examining the focus of the current review. The two primary themes; comfort and pain search topics applicable to the lower extremity

(Table 2.1, search 1 and 4), provided a total of N= 976 comfort themes, which was fewer than pain measurement publications (N=1141).

2.4.2 Lower limb key word search and comfort in football and physical activity

Peer-reviewed journal publications with themes exploring any facet of self-rated comfort and pain measures associated with the lower extremity were extracted. The term lower limb was used interchangeably with lower extremity, lower leg and limb. The region included the anatomical areas feet, ankle, calf and / or Achilles, shin, knee and shoes and / or footwear, and / or football boots. The search terms were combined with descriptive words for physical comfort (Table 2.1, search 1). In compliance with the aim of the review, the next level of searching included key words relating to the football codes relevant to the purpose of the study (Australian Football, Rugby League and Rugby Union). Although football (soccer) was not an area of research conducted in the thesis research, the code was used as part of the search strategy, because of its dominance as a global sport and the possibility that comfort related themes may be missed if not included. For the sake of completeness, American football (Gridiron) was also included but produced no relevant search results (Table 2.1, search 2).

Given the nil result from the inclusion of the football codes, lower limb and physical comfort terms were combined with more generic terms for movement (exercise, sport, physical activity). However, again, results provided limited numbers (N=12) of relevant publications (Table 2.1, search 3). Three additional publications were extracted by manually searching the references of the publications obtained using the database search. In total, 15 comfort publications were considered relevant.

2.4.3 Lower limb key word search and pain in football and physical activity

To include the potentially related literature, we again used the same searches on lower limbs, football codes and more generic movement terms to publications describing perceptions of pain (Table 2.1, search 4). After exclusion of non relevant themes, a total of 81 publications were related to lower extremity and expanded pain keywords (Table 2.1, search 5). A further 39 publications were excluded when the themes were applied to physical activity.

2.4.4 Comfort and pain in football and physical activity

After removing duplicate publications, and publications not using self-rated measures for either comfort or pain, left 57 publications that related to the combined themes of comfort (15) and pain (42 publications), sport, or physical activity, and lower extremities. In seeking football relevant studies, all 15 of the comfort related publications were removed as they did not relate to football. A further 33 pain related publications were excluded for the same reason. This included a double blind trial involving pain in an elite group of Australia Football players because it did not meet the criteria set for anatomical sites in this review Huguenin, et al., (2005). A study of knee pain, which included football was also excluded as the majority of participants had a mean age of <18years (Gerbino, et al., 2006). These exclusions resulted in nine remaining publications. However, none were inclusive of lower extremity comfort (Table 2.1, search 3 and 6).

The final publications selected for discussion are detailed in Tables 2.2 and 2.3. Due to the absence of comfort in football research, the 15 publications associated with comfort and physical activity were used in the current review to highlight how aspects of comfort, previously examined in isolation, are indeed relevant to football (Table 2.2). Self-rated lower extremity pain was analysed in nine publications (Table 2.3).

2.4.5 Pain-discomfort related publications

Of the lower extremity pain related publications, the nine publications extracted involved 339 players from various football codes. All the studies were published in peer review journals between 2001 and 2009. The size of the studies ranged from 10 to 126 participants. The age of participants ranged from 18 to 42 years. Most (seven of nine) studies were conducted in Europe, all from countries in which football (soccer) is the national sport. Therefore, not surprisingly six of the European studies examined soccer alone. The remaining European study was from Germany and examined a variety of sports including the football codes soccer, American football and rugby. Two of the studies were from North America (Canada and United States) and also included soccer.

Self reported pain measurement occurred in all nine studies. The most popular measure of pain was a Visual Analogue Scale (VAS). The design of the VAS used in all the studies was similar. Seven of the studies used a 100-mm visual analogue scale (VAS), a scale frequently used in clinical medicine to record pain. The other two studies used variations of numerical rating scales for assessment. Specific to the VAS, no inter-study variation was observed on the labelling of the VAS. The left end of the scale was anchored with zero (“no pain”), the right-end anchored with ten (“severe pain”). However, variations occur in the interpretation of VAS by subjects. Therefore, comparisons cannot be made between the studies in relation to outcome results.

Eight of the nine studies assessing pain were prospective in design. The other study was a descriptive study of knee pain associated with osteoarthritis in retired elite footballers, compared to a non sporting group. Four of the prospective studies were intervention designs. Two of three intervention studies investigated muscle soreness in soccer and futsal. Impellizzeri & Maffiuletti (2007) and Jönhagen, Ackermann, & Saartok (2009) compared forms of plyometric exercises on muscle pain in amateur soccer players, while different recovery strategies in futsal on muscle soreness were compared (Tessitore, et al., 2008). A variety of self-rating systems were used to measure muscle pain. The relevance of self-rated muscle pain in these studies for comfort is to determine the efficacy of treatment regimes.

One pain-discomfort study compared a VAS and 7-point Likert scale to measure lower extremity muscle soreness (Impellizzeri & Maffiuletti, 2007). A conclusion from the data was a Likert scale was a reliable method for footballers to self-rate lower extremity discomfort. Of the two studies that measured pain-discomfort with systems other than VAS, a Likert scale was also used in a later study by the same group (Impellizzeri, et al., 2008) to indicate how a self-rating system was useful determining muscle soreness associated with a football specific training drill. The other study extracted, used an 11-point numerical rating scale to measure muscle soreness (Tessitore, et al., 2008).

2.4.6 Comfort related publications

The publications relevant to lower extremity comfort determination by self-rating systems were confined to one decade. The range of publications extracted spanned the years 2001-2010 and were limited to 11 research groups. Six of the 15 publications were extracted from two groups of researchers. Of the 15 publications retrieved, 13 had footwear themes. The majority of studies had less than 30 participants, but two military studies had more than 100 participants. The age of participants ranged from 19 to 45 years and one study failed to record ages (Wegener, et al., 2008). North America dominated the comfort research (eight publications); with four being conducted by the one research group from the University of Calgary (Mündermann, Nigg, Neil Humble, & Stefanyshyn, 2003a; Mundermann, et al., 2003b; Mundermann, et al., 2002; Mundermann, et al., 2001). The remaining research emanated from Australia (2), Europe (3) and United Kingdom (2). Unlike the pain studies, none of the comfort relevant publications extracted involved team sports and so field studies were confined to two military studies (Birrell & Haslam, 2009; Mundermann, et al., 2001) and a large group (N=146) of amateur tennis players (Llana, Brizuela, Dura, & Garcia, 2002). The tennis study was the only study extracted to investigate a specific sport, tennis.

The majority of the studies investigated relationships between perceived comfort and footwear. These studies were not field relevant, but laboratory based (12 publications). Running was the most common activity studied (11 publications), with four research areas involving the combined activities of running and walking. Orthotic devices of various styles were used in eight of the studies. Two publications involved comfort assessment of footwear conditions with various lacing techniques (Hagen & Hennig, 2009; Hagen, Homme, Umlauf, & Hennig, 2010). The only study not to involve footwear was a musculoskeletal questionnaire of military personnel (Birrell & Haslam, 2009).The study was a retrospective observational military study assessing skeletal discomfort with a comfort questionnaire. The preferred method of measuring comfort was the use of a 100mm or 150mm visual analogue scale (nine studies) while a numerical rating-Likert scale was used in six studies. One study assessed footwear comfort using three self-rating scales and concluded the VAS to be the most reliable method (Mills, Blanch, & Vicenzino, 2010). This was in contrast to a self-rating lower extremity pain study (Impellizzeri & Maffiuletti, 2007) who preferred a Likert scale for relevance. The study by Kong & Bagdon (2010) used a direct question technique for participants to record shoe preferences.

Table 2.1 *Search strategy and results.*

Search terms		CINAHL	PsycINFO	Ovid MEDLINE	SportDiscus	Scopus
Search 1						
Lower limb exp *or* foot *or* ankle *or* shin *or* calf *or* Achilles *or* knee *or* footwear exp AND Physical Comfort exp	*Total number of searched publications*	**30**	**23**	**83**	**192**	**648**
	Articles excluded due to surgical theme	**20**	**13**	**43**	**136**	**441**
	Articles excluded due to relevance and duplication	**1**	**4**	**17**	**42**	**162**
	Remainder of potentially relevant publications	**9**	**6**	**23**	**14**	**45**

Search terms		CINAHL	PsycINFO	Ovid MEDLINE	SportDiscus	Scopus
Search 2						
Lower limb ^{exp} *or* foot *or* ankle *or* shin *or* calf *or* Achilles *or* knee *or* footwear ^{exp} AND Physical Comfort ^{exp} AND Rugby ^{exp} or football ^{exp} or soccer or Australian rules	*Total number of searched publications*	**nil**	**nil**	**nil**	**nil**	**nil**
	Articles excluded due to surgical theme	**nil**	**nil**	**nil**	**nil**	**nil**
	Articles excluded due to relevance and duplication	**nil**	**nil**	**nil**	**nil**	**nil**
	Remainder of potentially relevant publications	**nil**	**nil**	**nil**	**nil**	**nil**

Search terms		CINAHL	PsycINFO	Ovid MEDLINE	SportDiscus	Scopus
Search 3						
Lower limb ^{exp} *or* foot *or* ankle *or* shin *or* calf *or* Achilles *or* knee *or* footwear ^{exp}	*Total number of searched publications*	**7**	**11**	**30**	**23**	**34**
AND	*Articles excluded due to surgical theme*	**3**	**9**	**22**	**14**	**19**
Physical Comfort ^{exp} AND	*Articles excluded due to relevance and duplication*	**2**	**1**	**8**	**5**	**10**
Physical exercise *or* physical activity *or* sport	*Remainder of potentially relevant publications*	**2**	**1**	**nil**	**4**	**5**

Search terms		CINAHL	PsycINFO	Ovid MEDLINE	SportDiscus	Scopus
Search 4						
Lower limb ^{exp} *or* foot *or* ankle *or* shin *or* calf *or* Achilles *or* knee *or* footwear ^{exp} AND Pain measurement or pain scale or visual analogue scale	*Total number of searched publications*	**352**	**124**	**88**	**224**	**353**
	Articles excluded due to surgical theme	**200**	**108**	**63**	**117**	**327**
	Articles excluded due to relevance and duplication	**111**	**5**	**18**	**89**	**20**
	Remainder of potentially relevant publications	**41**	**11**	**7**	**18**	**6**

Search terms		CINAHL	PsycINFO	Ovid MEDLINE	SportDiscus	Scopus
Search 5						
Lower limb ^{exp} *or* foot *or* ankle *or* shin *or* calf *or* Achilles *or* knee *or* footwear ^{exp}	*Total number of searched publications*	**37**	**37**	**96**	**8**	**33**
AND	*Articles excluded due to surgical theme*	**18**	**22**	**56**	**4**	**25**
Pain measurement ^{exp} *or* pain scale ^{exp} *or* visual analogue scale ^{exp} AND	*Articles excluded due to relevance and duplication*	**7**	**8**	**23**	**1**	**5**
Physical exercise *or* physical activity or sport	*Remainder of potentially relevant publications*	**12**	**7**	**17**	**3**	**3**

Search terms		CINAHL	PsycINFO	Ovid MEDLINE	SportDiscus	Scopus
Search 6						
Lower limb [exp] *or* foot *or* ankle *or* shin *or* calf *or* Achilles *or* knee *or* footwear [exp]	*Total number of searched publications*	**5**	**7**	**14**	**5**	**nil**
AND	*Articles excluded due to surgical theme*	**1**	**3**	**7**	**1**	**nil**
Pain measurement or pain scale or visual analogue scale						
AND	*Articles excluded due to relevance and duplication*	**1**	**4**	**4**	**1**	**nil**
Rugby [exp] or football [exp] or soccer or Australian rules						
	Remainder of potentially relevant publications	**3**	**nil**	**3**	**3**	**nil**

Table 2.2 *Football pain studies using self-rated pain measures.*

Name of published study	Author and year	Origin of research	Participants (N) Gender	Age years (SD)	Code of football	Anatomical site	Pain measure
1. Convergent evidence for construct validity of a 7-point Likert scale of lower limb muscle soreness.	Impellizzeri & Maffiuletti (2007)	Switzerland	N= 26 Gender not stated	25 (4)	Soccer amateur	Lower extremity muscle soreness	Comparison between 100mm VAS and 7-point Likert scale
Experimental design: Field setting. Prospective collection of data, 28 occasions using a self administered questionnaire over four weeks. **Outcome measure*:** Perceived lower extremity muscle soreness using two pain scale methods indicating construct validity for Likert scale. **Relevance:** Subjective pain ratings have relevance to football for the determination of lower extremity muscle pain.							
2. Knee osteoarthritis in 50 former top-level footballers: A comparative (control group) study	Elleuch, et al., (2008)	France	N= 50 Male	49 (4)	Soccer elite and non sport participants	Knee	VAS 100mm

Name of published study	Author and year	Origin of research	Participants (N) Gender	Age years (SD)	Code of football	Anatomical site	Pain measure
Experimental design: Field setting. Retrospective, descriptive study over a two year period. Two groups (retired elite footballers and control group). **Outcome measure*:** Knee pain. **Relevance:** Perceived discomfort-pain measures can be used in elite football.							
3. Eccentric rehabilitation exercise increases peritendinous type I collagen synthesis in humans with Achilles tendinosis	Langberg, et al., (2007)	Denmark	N= 12 Male	26 (1)	Soccer elite	Achilles	VAS 100mm
Experimental design: Laboratory setting. Prospective measure of Achilles loading pain between two groups over a 12 week period. **Outcome measure*:** Achilles tendon pain before and after intervention. The injured tendon group improved pain scores. No change to healthy controls. **Relevance:** Subjective pain rating scales used in elite soccer to measure improvement of Achilles pain (from discomfort to comfort). Thus measures of discomfort or comfort might be a useful measure of return to play following injury.							

Name of published study	Author and year	Origin of research	Participants (N) Gender	Age years (SD)	Code of football	Anatomical site	Pain measure
4. Forward lunge: a training study of eccentric exercises of the lower limbs	Jönhagen, et al., (2009)	Sweden	N= 32 Male	18 (na)	Soccer amateur	Lower extremity muscle soreness	VAS 100mm
Experimental design: Laboratory setting. Prospective randomised 6 week study. Three groups inclusive of a control and two groups who performed a plyometric exercise drill. **Outcome measure*:** Muscle pain following specific exercise drill using a subjective pain scale. **Relevance:** Subjective ratings are clinically useful in football as a measure of correlation data between specific muscle training, soreness and performance indicators.							
5. Effectiveness of active versus passive recovery strategies after futsal games	Tessitore, et al., (2008)	Italy	N= 10 Male	23 (2)	Soccer semi-elite futsal	Lower extremity muscle soreness	11-point numerical rating scale

Name of published study	Author and year	Origin of research	Participants (N) Gender	Age years (SD)	Code of football	Anatomical site	Pain measure
Experimental design: Field & Laboratory setting. Prospective randomised cross-over study with allocation of participants to one of four groups. **Outcome measure*:** Muscle pain ratings following different post-game recovery strategies. **Relevance:** Subjective rating systems within football show versatility in measurement for different recovery strategies.							
6. The relationship between self-reported and clinical measures and the number of days to return to sport following acute lateral ankle sprains	Cross, Worrell, Leslie, & Van Veld (2002)	USA	N= 20 Male & Female	19 (1)	Variety of sports including soccer	Ankle	VAS 100mm
Experimental design: Field setting. Prospective observational study. **Outcome measure*:** Return to sport using a combination of subjective assessment and functional tests. **Relevance:** Self-reported measures can be used as a method to assist with return to play predictions.							

Name of published study	Author and year	Origin of research	Participants (N) Gender	Age years (SD)	Code of football	Anatomical site	Pain measure
7. Effect of plyometric training on sand versus grass on muscle soreness and jumping and sprint ability in soccer players	Impellizzeri, et al., (2008)	Italy	N= 37 Male	25 (4)	Soccer amateur	Lower extremity muscle soreness	7-point Likert scale

Experimental design: Field setting. Parallel two group, randomised four week study.

Outcome measure*: Changes in muscle soreness between the two groups.

Relevance: Muscle soreness derived from different training regimes can be measured by self-rating systems which will assist the development of individualised prehabilitation and training programs.

Name of published study	Author and year	Origin of research	Participants (N) Gender	Age years (SD)	Code of football	Anatomical site	Pain measure
8. A randomised clinical trial of the efficacy of drop squats or leg extension / leg curl exercises to treat clinically diagnosed jumper's knee in athletes: pilot study	Cannell, Taunton, Clement, Smith, & Khan (2001)	Canada	N= 19 Male & Female	26 (na)	Variety of sport including soccer and American football	Knee	VAS 100mm

Experimental design: Clinical setting. Prospective, randomised controlled intervention study, twelve weeks.

Outcome measure*: Leg pain.

Relevance: Limb affected by pain can be measured using a comfort scale which will assist with decision management of the athlete.

Name of published study	Author and year	Origin of research	Participants (N) Gender	Age years (SD)	Code of football	Anatomical site	Pain measure
9. Efficacy and tolerability of Escin/Diethylamine salicylate combination gels in patients with blunt injuries of the extremities	Pabst, Segesser, Bulitta, Wetzel, & Bertram (2001)	Germany	N= 126 Male & Female	28 (9)	Variety of sports including American football, soccer, rugby	Lower extremity	VAS 100mm

Experimental design: Clinical setting. Prospective randomised controlled double-blind study. Four parallel treatment groups.

Outcome measure*: Pain.

Relevance: VAS scales used to measure injuries associated with football.

-- Outcome measure The study may have included other outcomes measures not relevant to a self-rated descriptions.*

-- na = not available.

-- Age Where age not stated in years, range given.*

Table 2.3 *Comfort studies of physical exercise using self-rated systems*

Name of Published Study	Author and Year	Origin of Research	Participants (N) Gender	Age Years (SD)	Code of Football	Anatomical Site	Comfort Measure
1. Effect of cushioned insoles on impact forces during running	O'Leary, Vorpahl, & Heiderscheit (2008)	USA	N= 16 Male & Female	Range: 20-36	Recreational running	Lower extremity / footwear (cushioned insoles)	VAS 100mm

Experimental design: Laboratory setting. Prospective observational randomised intervention trial. Two groups, two conditions (insert & no insert), five running trials, same comfort measures.

Outcome measure: Perceived footwear comfort with two insole conditions.

Relevance to football: Comfort identified as a useful method for the determination of the perceived effectiveness relative to comfort.

Name of Published Study	Author and Year	Origin of Research	Participants (N) Gender	Age Years (SD)	Code of Football	Anatomical Site	Comfort Measure
2. Effects of different shoe-lacing patterns on dorsal pressure distribution during running and perceived comfort	Hagen, et al., (2010)	Germany	N= 14 Male	24 (5)	Running	Foot / footwear	7-point Likert scale

Name of Published Study	Author and Year	Origin of Research	Participants (N) Gender	Age Years (SD)	Code of Football	Anatomical Site	Comfort Measure
Experimental design: Laboratory setting. Prospective observational intervention trial. One group, four conditions, five trials per condition, same comfort measures.							
Outcome measure: Perceptions of shoe comfort and stability with different lacing conditions.							
Relevance to football: Comfort assessment of footwear conditions with various lacing techniques.							
3. Orthotic comfort is related to kinematics, kinetics and EMG in recreational runners	Mundermann, et al., (2003b)	Canada	N= 21 Male & Female	25 (6)	Recreational runners	Footwear / orthotics (Custom orthotics)	VAS 150 mm
Experimental design: Laboratory setting. Prospective randomised observational intervention trial. Four orthotic conditions (1 control and 3 prescription orthotics); 108 running trials per subject.							
Outcome measure: Comfort assessment of footwear conditions using prescription orthotics.							
Relevance to football: Footwear comfort is enhanced with orthotics, but is an individual phenomenon. Given the running demands associated with football, footwear is an important factor. Footwear selection may be modified based upon quantitative data.							

Name of Published Study	Author and Year	Origin of Research	Participants (N) Gender	Age Years (SD)	Code of Football	Anatomical Site	Comfort Measure
4. Relationship between footwear comfort of shoe inserts & anthropometric and sensory factors	Mundermann, et al., (2001)	Canada	N= 206 Male & Female	29 (7)	Military	Footwear / orthotics Lower extremity injury	VAS 100 mm

Experimental design: Field setting. Prospective intervention trial conducted over 4 months. Two groups; Insert group (six insert conditions), control group (nil insert).

Outcome measure: Perceived comfort of footwear using one of six insole conditions.

Relevance to football: Comfort and injury outcomes are associated with footwear conditions. Individuals are capable of determining different comfort situations associated with footwear conditions.

5. Development of a reliable method to assess footwear comfort during running	Mundermann, et al., (2002)	Canada	N= 9 Male & Female	27 (5)	Recreational runners	Footwear (inserts)	VAS 150 mm

Name of Published Study	Author and Year	Origin of Research	Participants (N) Gender	Age Years (SD)	Code of Football	Anatomical Site	Comfort Measure

Experimental design: Laboratory setting. Prospective randomised observational intervention study. One group 4 orthotic conditions, repeated measures x10.

Outcome measure: Reliability of a VAS footwear comfort scale.

Relevance to football: Comfort assessment of footwear provides reliable results.

Name of Published Study	Author and Year	Origin of Research	Participants (N) Gender	Age Years (SD)	Code of Football	Anatomical Site	Comfort Measure
6. Consistent immediate effects of foot orthoses on comfort and lower extremity kinematics, kinetics and muscle activity	Mundermann, Nigg, Humble, & Stefanyshyn (2004)	Canada	N= 21 Male & Female	25 (6)	Recreational runners	Footwear / orthotics (Custom orthotics)	VAS 100mm

Experimental design: Laboratory setting. Observational intervention trial One group. Four orthotic conditions (1 control and 3 prescription orthotics); Repeated measures (9 sessions x12 trials per subject).

Outcome measure: Insert-footwear comfort using a VAS.

Relevance to football: Perceived comfort can be altered by footwear conditions such as the use of prescription orthotic inserts. Thus the use of comfort to measure individual comfort might provide more relevant footwear-orthotic prescription guidelines.

Name of Published Study	Author and Year	Origin of Research	Participants (N) Gender	Age Years (SD)	Code of Football	Anatomical Site	Comfort Measure
7. A comparison of semi-custom and custom foot orthotic devices in high- and low-arched individuals during walking	Zifchock & Davis (2008)	USA	N= 37 Male & Female	24 (6)	Walking	Footwear / foot	7-point Likert scale
Experimental design: Laboratory setting. Prospective observational randomised intervention trial One group, 3 orthotic conditions, repeated measures (2 orthotics; 1 control, x5 trials). **Outcome measure:** Orthotic effects on comfort. **Relevance to football:** Perceived comfort used to measure therapeutic interventions.							
8. Effect of neutral-cushioned shoes on plantar pressure loading and comfort in athletes with cavus feet: a crossover randomized controlled trial	Wegener, et al., (2008)	Australia	N= 22 Male & Female	na	Running	Footwear	VAS 150 mm

Name of Published Study	Author and Year	Origin of Research	Participants (N) Gender	Age Years (SD)	Code of Football	Anatomical Site	Comfort Measure
Experimental design: Laboratory setting. Prospective cross-over randomised intervention trial. One group, 3 shoe conditions (2 cushioned running shoes; 1 control shoe).							
Outcome measure: Footwear comfort measured by a VAS.							
Relevance to football: Comfort used to measure footwear preferences & offers clinical guidelines for shoe selection relative to foot pain.							
9. Do you get value for money when you buy an expensive pair of running shoes?	Clinghan, Arnold, Drew, Cochrane, & Abboud, (2008)	United Kingdom	N= 43 Male	29 (9)	Walking and running	Footwear	VAS 100 mm
Experimental design: Laboratory setting. Prospective observational randomised intervention trial. One group, 10 shoe conditions (9 running shoes; 1 control barefoot).							
Outcome measure: Loading forces while walking & running in three different shoes Comfort measures of walking & running in different shoes							
Relevance to football: Comfort can be utilized to measure perceived differences in footwear styles associated with cost and footwear preferences. A cost-benefit analysis of footwear comfort may be beneficial to amateur footballers who do not have footwear sponsorship arrangements.							

Name of Published Study	Author and Year	Origin of Research	Participants (N) Gender	Age Years (SD)	Code of Football	Anatomical Site	Comfort Measure
10. Identifying clinically meaningful tools for measuring comfort perception of footwear	Mills, et al., (2010)	Australia	N= 20 Male & Female	24 (3)	Treadmill walking and running	Footwear /inserts (commercially available inserts)	VAS 100mm & 7-point Likertscale

Experimental design: Laboratory design. Prospective randomised observational 2 groups, 5 conditions (4 generic orthotics; 1 no insert). Repeated measures with two comfort measure scales (5 sessions x 4 trials of walking and 4 trials running).

Outcome measure: Footwear comfort using two self-rating scales.

Relevance to football: Varying comfort scales are capable of assessing footwear conditions.

11. Subjective skeletal discomfort measured using a comfort questionnaire following a load carriage exercise	Birrell & Haslam, (2009)	United Kingdom	N= 127 Male & Female	21 (2)	Military	Lower extremity including hip and back	5-point numerical rating scale

Name of Published Study	Author and Year	Origin of Research	Participants (N) Gender	Age Years (SD)	Code of Football	Anatomical Site	Comfort Measure
Experimental design: Field setting. Retrospective observational study of discomfort following exercise (one data collection period).							
Outcome measure: Skeletal discomfort derived from a comfort questionnaire.							
Relevance to football: The implementation of comfort rating scales in large groups is viable and easily implemented, and transferrable to a football cohort.							
12. Effects of different shoe-lacing patterns on the biomechanics of running shoes	Hagen & Hennig (2009)	Germany	N= 20 Male & Female	32 (10)	Running	Footwear	7-point Likert
Experimental design: Laboratory setting. Prospective randomised observational intervention trial. Six footwear conditions altered by different lacing conditions.							
Outcome measure: Comfort assessment of footwear conditions with various lacing techniques.							
Relevance: Comfort measures between individuals are different and dependent upon the footwear condition such as footwear fit-closure.							

Name of Published Study	Author and Year	Origin of Research	Participants (N) Gender	Age Years (SD)	Code of Football	Anatomical Site	Comfort Measure
13. Shoe preference based on subjective comfort for walking and running	Kong & Bagdon (2010)	USA	N= 41 Male & Female	27 (9)	Running & walking	Footwear	Statement of shoe preference by participants

Experimental design: Laboratory setting. Retrospective descriptive study using qualitative measures. Three footwear conditions, repeated measures x20 trials walking and running.

Outcome measure: Footwear comfort measures.

Relevance to football: Shoe preference varies among individuals and activity. Therefore, footwear comfort measures in football of individuals might be of benefit in assisting footwear selection.

Name of Published Study	Author and Year	Origin of Research	Participants (N) Gender	Age Years (SD)	Code of Football	Anatomical Site	Comfort Measure
14. A comparison of rearfoot motion control and comfort between semicustom foot orthotic devices	Davis, Zifchock, & DeLeo (2008)	USA	N= 19 na	Range: 19-45	Running & walking	Orthotics-footwear	VAS

Name of Published Study	Author and Year	Origin of Research	Participants (N) Gender	Age Years (SD)	Code of Football	Anatomical Site	Comfort Measure
Experimental design: Laboratory setting. Randomised prospective trials. Three conditions (no orthotic, semi-custom and custom) x 5 running and x 5 walking trials.							
Outcome measure: Differences in orthotic comfort between custom and semi-custom orthotics.							
Relevance to football: Comfort measures are relevant to the assessment of therapies such as orthotics conditions which might be of assistance to both footballers and medical staff in determining strategies to improve the preparation of footballers.							
15. A study of the discomfort associated with tennis shoes	Llana, et al., (2002)	Spain	N= 146 Male & Female	26 (8)	Tennis	Footwear	7-point Likert
Experimental design: Field Setting. Retrospective measure of comfort using interviews x1 occasion.							
Outcome measure: Perceived comfort of tennis shoes.							
Relevance to football: Measures of comfort can be implemented across a variety of sports.							

-- Outcome measure The study may have included other outcomes measures not relevant to a self-rated descriptions.*

-- na = not available.

-- Age Where age not stated in years, range given.*

2.5 DISCUSSION

The systematic review of literature resulted in no lower extremity comfort studies in football. A probable reason for the paucity of well designed prospective field studies in professional sport is that research in the domain of elite sport is difficult to conduct. Professional sport by its nature is demanding of players, medical, conditioning and coaching staff. The intrusion of large research projects into football organisations is difficult to manage for reasons ranging from player compliance reasons, to confidentiality of potentially sensitive information pertaining to individual players and to the football organisation. Furthermore, studies need to be conducted over multiple weeks, where conditions do not remain stable, players may not be available to test and difficulties arise in maintaining participant motivation.

2.5.1 Lower extremity pain-discomfort studies in football

A common theme to emerge from the pain-related publications was the widespread use of self-rating systems. A number of different self-rating systems were used. Researchers obviously gravitate to a particular system for many reasons, but it was not a conclusion drawn from this search that any system was less effective than another. For pain themes, nine studies specific to self-rated measures of lower extremity pain themes in football were extracted. Only one publication involved professional football (Elleuch, et al., 2008) and one study elite Futsal (Langberg, et al., 2007). Seven studies were associated with amateur footballers (Table 2.2). This result reinforces the notion of the difficulty of conducting research in professional football.

The epidemiology of football injuries related to the lower extremity is well documented. Eight years of lower limb injury data extracted from the Australian Football League Injury Surveillance project describes the prevalence of injury to the knee, shin, calf-Achilles, ankle and foot in Australian Rules Football (Orchard & Seward, 2008). However, the current review revealed only some of these anatomical areas was addressed in football. Studies of self-rated pain involving football were not available for the foot and shin. The most common anatomical site researched was muscle soreness (five), followed by the knee (two studies). The ankle and Achilles were examined in one study. Footwear is another area of the search strategy not resulting in any studies specific to pain or discomfort in football. The inclusion of footwear as an anatomical segment was considered viable as football boots are common to all football codes and it is speculated that footwear plays a role in injury and comfort (Lake, 2000). Common footwear factors previously addressed include traction (Milburn & Barry, 1998) ground surfaces (Orchard, 2002) and boot design (Grund & Senner, 2006).

2.5.2 Lower extremity comfort and relevance to football

The comfort paradigm using self-rating measures permeates areas of biomechanics, footwear, military, and clinical medicine, but results of the current review indicate comfort is infrequently used in evaluation of sports injury. The lack of comfort research into football is surprising because differences in comfort as small as 10% may have clinical relevance (Davis, et al., 2008). Therefore, comfort measures may have a role in determining optimal conditions for individuals.

Comfort as a paradigm in medicine and nursing has been well established for many years, but the use of comfort relevant to sports medicine and biomechanics is a relatively new concept. The systematic review covered 20 years (1990-2010), but the comfort publications extracted were confined to the years 2001-2010. The narrow range of comfort research years confirms the infancy of comfort paradigms within sports medicine and that the concept has not been explored within the football codes.

Furthermore, only a small number of researchers have assessed comfort and physical activity. Six of the 15 publications extracted were from two groups of researchers. The series of studies by Mundermann et al. (2001-2004), were instrumental in the development of footwear comfort assessment as a measure of injury in physical activity. Our extraction of comfort relevant research to the lower extremity identified that running and footwear comfort were most common. Of the 15 publications retrieved, 13 had footwear themes. While these studies were not football specific, the publications show footwear-comfort effects. An area of research not found within the literature was the effect of football boots on lower extremity comfort. Running and footwear comfort themes have high relevance to football and lower extremity comfort, because running imposes a high impact and is germane to all football codes. Distances covered by individuals in the various codes have recorded footballers running upward of 13 kilometres (km) in Australian Rules (Gray & Jenkins, 2010), 7 km in the rugby codes (Cunniffe, Proctor, Baker, & Davies, 2009), and 12 km in football-soccer (Rampinini, Coutts, Castagna, Sassi, & Impellizzeri, 2007).

Previous research indicates repetitive loading of the lower extremity range from 1.5 to 5 times body weight (Cavanagh & Lafortune, 1980; Hreljac, Marshall, & Hume, 2000), resulting in microtrauma. Repetition of these running stressors is associated with musculoskeletal injury (Lake & Lafortune, 1998; O'Leary, et al., 2008). Therefore, cushioning properties of shoes and insoles might be important to football, but only one study to date has used laboratory settings to examine this perspective of footwear (Wegener, et al., 2008).

While, the field testing of load forces is difficult to study, the use of comfort ratings to football boots will provide information about perceived comfort between styles of football boots and may extend to different environmental conditions. Past research speculated climate changes were associated with lower extremity injury in AFL (Orchard & Seward, 2002). Therefore, any conclusions about climate and ground surfaces being risks for injury should also include footwear. Chapters 6 and 7 detail prospective studies of football that footwear comfort is an important criteria for injury outcomes.

These studies strengthen the rationale for future research into the role of comfort and football boots, an area which was not identified from the systematic review. Football boots are used in all forms of elite and amateur football codes and as such are an integral component of fundamental equipment.

The most popular method used to assess comfort was a VAS 100mm version. The construction of the VAS and other scales from the studies extracted were similar to pain scale descriptions. Like pain scales, in which increasing scores represent increased pain, comfort measures can adopt the same principles. In the studies extracted, the VAS was anchored at the left with “poor comfort” and the right with terms such as “most comfortable”. Similarly, the Likert scales used low numbers to delineate poor comfort and high numbers good comfort in all but one study (Birrell & Haslam, 2009) where low numbers represented “comfortable” and higher numbers indicated a progression toward discomfort. It would appear from the interpretation of the studies, that the type of self-rating scale used does not effect the overall interpretation by individuals and thus does not distort results.

The literature remains unclear about the preferred method for assessing comfort. However, two previous studies addressing comfort (Mills, et al., 2010; Mundermann, et al., 2002), advocate VAS as a more reliable method than Likert in the measurement of footwear comfort. Despite these preferences it is likely that reliability of various self-rating measures is dependent upon study design, interpretation of the scale and motivation of respondents (Mills, et al., 2010). Therefore, it is likely that success or failure to obtain meaningful data is dependent upon how the self-rating scales are contextualised and delivered within the study design.

2.5.3 Limitations of study

The search was limited to the five accessible electronic databases that included the most common journals. The search strategy classified publications based on the themes specific to lower extremity comfort. Because of the paucity of comfort as a theme within the sports medicine literature we included the term pain, but publications may have been missed due to the vast array of pain and injury terms which are commonly used in the sports medicine literature. However, the trends observed were so large that any potential misclassification is highly unlikely to affect the overall interpretation.

2.5.4 Future directions

The dominance of footwear as the theme in comfort studies highlights the infancy of comfort as a theme applicable to the musculoskeletal system and sport-physical activity generally. The nil response for comfort themes and football represents a gap in the research literature and provides scope for much needed investigation. Additionally, the majority of studies were laboratory based. Given the controlled environment the studies were generally conducted, the relevance of data to field environments should be considered, providing scope for relevant field studies.

Measures of pain and discomfort within clinical medicine and sport have been extensively used by clinicians and researchers as a method to evaluate techniques aiming to improve the prevention and management of musculoskeletal dysfunction. However, measurement of pain and discomfort can be considered a reactive response. An alternate approach is a measure of musculoskeletal well-being that occurs prior to injury or pain. This concept can be considered a measure of physical comfort, the opposite of pain.

Therefore, a theme of this thesis is a concept that requires a paradigm shift in the application of self-rating scales. Instead of investigating the outcome effect of an intervention (e.g. Achilles eccentric loading programs, the use of orthotics on foot-leg pain, the efficacy of knee taping on injured knees), a measure of real-time (current) musculoskeletal well-being provides a point in-time for describing an individual comfort relative to other times of measurement. Once a baseline of comfort can be established for an individual, future comfort perceptions can be benchmarked against a known quantity. No studies have proposed or investigated a measure of lower limb comfort which is applicable to the football codes.

2.6 CONCLUSIONS

Research in the area of lower extremity comfort is under represented and is a concept not previously investigated within professional football. Pain is a theme more commonly cited in football injury literature. This systematic review of the literature provides impetus for future football specific research which might contribute to the development of a lower extremity comfort paradigm specific to the football codes.

The results provide strong evidence that comfort theories currently established in other clinical settings might have relevance to football. Indeed, the fields in which comfort concepts exist, involve physical activity (running) and equipment (footwear), which are both fundamental to football. The use of comfort in running based activities provides impetus to investigate the relevance of comfort concepts within all football codes and might represent one of the greatest opportunities to establish another level of theory and practice to sports injury detection and management.

CHAPTER THREE

DEVELOPMENT OF A NOVEL RATING SYSTEM TO ASSESS LOWER EXTREMITY COMFORT

This chapter is supported by the publication:

Kinchington, M., Ball, K., Naughton, G. (2011, September-October; in press). Development of a novel rating system to assess lower limb comfort. Journal American Podiatric Medical Association.

3.1 ABSTRACT

Background: Comfort evaluation techniques are common place in medicine. However, measures of lower extremity comfort are infrequently used in the sporting environment.

Objectives: Develop an instrument to measure lower extremity comfort in a cohort of professional footballers that will extend previous work in the field of injury awareness.

Methods: Professional footballers (N=40) from three codes of football played in Australia participated in the development of a Lower Limb Comfort Index (LLCI). The study comprised three stages. A critical appraisal of the literature established the need for a LLCI. The second stage involved 20 professional footballers establishing and testing the components of the comfort index as an instrument to measure comfort. Stage three consisted of footballers (N=20) pilot testing the reliability of the LLCI in a controlled environment.

Results: A paucity of relevant literature established a theoretical basis for the development of the LLCI. Non parametric statistics (McNemars test) in stage two indicated the LLCI demonstrated good responsiveness to suitability (P=0.019) and ease of use (P<0.01). Following a high level of agreement for responses, the third stage examined repeated measures of difference between two time periods for both sum comfort (ICC 0.99) and individual anatomical segments (Kappa range 0.72-1.0). The results provided confidence the comfort index was reliable.

Conclusions: The LLCI showed good trait construct to conduct a future study to investigate inter-rater consistency in a wider cohort of professional footballers under different conditions such as Match-day and training week environments.

3.2 INTRODUCTION

Comfort as a concept to measure wellbeing and intervention outcomes within medicine is increasingly utilised as a method of measuring pain or discomfort (Kolcaba & Steiner, 2000). Assessment of pain reduces to a very simple endpoint; an individual's perception of comfort (Dillard & Knapp, 2005). Comfort is the opposite of pain (discomfort) due to the interactive play of nociceptive stimulation and the cerebral cortex. Thus, the lack of pain stimuli via the neural networks of the body can be termed comfort (Karoly, Jensen, & Goldstein, 1987).

Comfort is a holistic state, transversing aspects of wellbeing that are physical, psycho-spiritual, social, and environmental (Kolcaba & Fisher, 1996). Perception of comfort is drawn from simultaneous and interrelated human experiences gathered over a period of time (Kolcaba, 1992). It is a real phenomenon drawn from human experience which is of no value to another individual. However, the concept of comfort lacks consensus within the literature and is difficult to define and to quantify (Hanspal, Fisher, & Nieveen, 2003; Mundermann, et al., 2002; Slater, 1985).

From a physical perspective, comfort affects common locomotor tasks such as walking and running (Miller, et al., 2000; Mundermann, et al., 2003b), and is correlated with skeletal alignment (Miller, et al., 2000). It is speculated that comfort is associated with fatigue and performance (Nigg, 2001; Nigg, et al., 1999) and can be influenced by footwear (McPoil, 2000; Nigg & Segesser, 1992). Anatomical regions inclusive of the foot, ankle and knee and footwear are commonly researched in areas inclusive of public health medicine, epidemiology, biomechanical, podiatric and physiotherapy because of the high prevalence, cost and morbidity of injury (Collinge & Simmonds, 2009). Statistics encompassing running-based sports indicate the majority of injuries sustained occur to the lower extremities (Guten & Adner, 1997; Kinchington, 2009 ; Taunton, et al., 2003). While the direct costs of lower extremity injury are difficult to quantify, the financial cost of overall sporting injuries has been calculated to be in excess of $A2 billion (Medibank, 2006). Specific to the football codes, using injury surveillance data (Orchard & Seward, 2008), the financial cost of lower extremity injury in one code of football played in Australia, calculated by this study in terms of wage costs relative to missed games exceeds $20 million per year.

Measures of comfort, which are recorded prospectively, may be important in determining physical performance and injury outcomes. A technique to monitor lower extremity comfort comprising key anatomical locations would offer the medical and sporting communities an effective screening instrument about the state of lower extremity health, and assist with injury prevention or early injury risk detection.

Comfort measures pertaining to footwear and the lower extremity commonly involve ordinal (Likert) scales (Impellizzeri & Maffiuletti, 2007; Orlando & King, 2004; Williams & Nester, 2006) or continuous scales such as visual analogue scales (VAS) (Chiu & Wang, 2007; Hong, et al., 2005; Mundermann, et al., 2003b). The reliability and validity of VAS as a psychophysical rating has been well documented (Boonstra, Schiphorst Preuper, Reneman, Posthumus, & Stewart, 2008; Chiu & Wang, 2007). A perceived advantage of VAS is the scale is not delimited by the discrete spacing of numerical ratings scales (Mundermann, et al., 2002). Some limitations of VAS include anchor words, the length of the scale, and the direction of the scale, among other factors (Eich, Reeves, Jaeger, & Graff-Radford,1985; Miller, et al., 2000).

Likert scales also measure comfort and demonstrate acceptable validity (Downie, et al., 1978; Lozano, García-Cueto, & Muñiz, 2008), minimal measurement error, are simple to comprehend, and so advantageous over VAS (Dijkers, et al., 2002). Signposts, which generally accompany Likert scales provides clear instruction for ease of interpretation and provides an even distribution of data rather than skewed data due to lack of signposts associated with VAS (Kolcaba & Steiner, 2000). However, limitations of Likert scales include the interpretation of specific anchors which will not be uniformly perceived by all respondents (Goldstein, Beer, & Hersen, 2004). A further limitation of a Likert scale occurs where comfort measures (ordinal) are evaluated with continuous measures such as grouped biomechanical variables (Miller, et al., 2000). However, individual comfort should not be analysed as a group statistic, such as an overall mean response, because comfort is an innately individual phenomenon (Hanspal, et al., 2003). Therefore, the use of Likert scales is appropriate to analyse individual comfort. A seven point scale is the most widely used response scale (Gaunt & O'Neill, 2007) enabling reasonable compromise between sensitivity, reliability, and ease of use (Bennett, Patterson, & Dunne, 2001).

3.3 METHODS

The purpose of this study was to develop an instrument to measure lower extremity wellbeing using comfort as the primary criterion. Likert-based comfort paradigms currently used extensively in medicine were considered fundamental to establish the lower extremity comfort scale. The development of an instrument termed; Lower Limb Comfort Index (LLCI) had three stages:

3.3.1 Stage one: critical appraisal

The critical appraisal for developing a LLCI derived impetus from:

I. Information accessible to the public from professional and consumer allied health organisations as well as legislative bodies who provide the community with information about the management and prevention of musculoskeletal injury.

II. A review of the medical and allied health literature for research, pertinent to the development of a LLCI and the contributions of comfort to musculoskletal well-being in sport. Electronic databases PubMed, CINHAL, Ovid Medline, The Cochrane Library, and PsychINFO up to and including February 2010 were searched. The search included all English language articles. The searches used the following key words *leg, footwear, shoe, musculoskeletal, injury, lower limb, comfort, wellbeing* and *measures*.

III. Anatomical segments which are prevalent in injury epidemiology studies, to develop a suitable LLCI. The medical and allied health literature was searched to establish segments for inclusion to develop the LLCI. The criterion for inclusion was based upon: (i) Gross anatomy of the lower extremity; (ii) Those anatomical areas which dominate injury epidemiology literature for running based activities (Figure 3.1).

3.3.2 Stage two: developmental stage

The developmental stage involved implementation and refinement of an experimental LLCI, based on a seven point Likert scale. The suitability of sign posts, the ease of administration, comprehension and suitability of the descriptive terms which accompanied the LLCI scale were examined.

Twenty participants with varying years of professional football experience from two codes of football (rugby league and Australian rules) volunteered to test the suitability of the LLCI for use in the field. Ethical approval was obtained from the Human Ethics Research Committee at Victoria University and participants completed informed consent declarations (Appendix B). Data from each participant were collected on a weekly basis for 18 weeks (360 responses). Versions of the LLCI were tested until all participants agreed with the format, determined by statistical merit. Each respondent completed a lower extremity comfort form under the instruction of either the researcher or head team trainer, who was well versed in the study. Each respondent was interviewed in a casual environment during the developmental stage to obtain feedback (Table 3.3). The LLCI was refined following respondent feedback.

3.3.3 Stage three: pilot reliability of LLCI

Once developed, the LLCI was piloted by 20 participants who were not involved in the development of the rating scale, but considered representative of the wider professional football community. Using reliability protocols previously established for footwear comfort (Miller, et al., 2000; Mundermann, et al., 2002; Mundermann, et al., 2001), the reliability of the LLCI was measured at 0 ^{hours} and 4 ^{hours} in a stable environment. Testing was performed on three separate occasions over a five day period with 48 ^{hours} between each session. To ensure the integrity of the test-retest condition there were no physical or medical interventions within the 4 ^{hour} period between the intra-test comfort data collection which may have altered the testing environment. In order to guard against recall bias, the order in which each anatomical segment was ranked was randomly assigned for each participant for each of the intra-test comfort collection sessions.

3.3.4 Statistical analysis

To measure whether the respondents changed their judgments of LLCI appraisal for *suitability*, *ease of use*, *anatomical descriptor suitability* and *sign post suitability* over the data collection periods during Stage One (developmental stage of LLCI), the data were cross-tabulated. McNemar’s test of agreement was used to determine if the number of players who responded with ‘agree’ changed significantly over time. Where no players responded with an ‘ambivalent’ or ‘disagree’ response these categories were combined because the main interest was to ascertain whether the percent of players who agreed with the tool had increased.

Reliability was estimated in Stage Three of the LLCI development, using absolute difference between time periods. The absolute differences in comfort index between the two time periods for the three days and for each anatomical segment were calculated. A paired t-test was used to compute mean difference and its standard deviation (SD). The measurement error was computed from the SD around the mean difference using the formula [(SD of differences / $\sqrt{2}$)* 1.96] (Bland & Altman, 1996). The error indicates a range above and below a measured comfort index in which it is expected a player's true comfort to lie. Where the comfort scores had the same category values on each occasion, reliability for each limb segment was also measured using Cohen's Kappa for which a value of one (1) indicates perfect agreement and a value of zero (0) indicates that agreement is no better than chance. For the sums of comfort scores, intra-class correlation coefficient (ICC) was computed to measure relative agreement between times using a one-way random model.

3.4 RESULTS

3.4.1 Stage one: critical appraisal

3.4.1.1 Qualitative clinical experience

The disciplines of allied health medicine inclusive of podiatric medicine ("American Academy of Podiatric Sports Medicine," 2010), sports medicine ("American College of Sports Medicine," 2010) and physiotherapy ("American Physical Therapy Association," 2010), are engaged with areas of injury associated with exercise and physical activity. Because of an increasing awareness of the costs associated with sport injury ("Sports Medicine Australia, Olympic Gold and Australia's Economy Harmed by Injuries, Media Release," 2008), peak bodies have been established globally to educate and train health professionals to provide advanced training for sports related injuries including the lower extremity. Such groups include International Federation of Sports Medicine ("International Federation of Sports Medicine ", 2010), International Olympic Commission Medical Commission ("Medical-Olympic," 2010) and National Sports Medicine organisations that provide consensus statements on sports participation including injury prevention, treatment and management. The information educates their professional membership and disseminates guidelines on injury prevention to the general public enabling successful empirical based interventions.

3.4.1.2 Literature review of injury and comfort

Integrative review of published literature in sports medicine, nursing, biomechanical and allied health medicine (podiatry and physiotherapy) provided information to support the development of the LLCI. The major areas of interest were; (i) injury epidemiology, (ii) comfort paradigms, and (iii) anatomical segments of the lower extremity with reoccurring injury themes.

3.4.1.2.1 Injury epidemiology

Epidemiology for exercise and sporting injury is difficult to quantify, however estimated direct financial costs range from A$ 830 million ("Medical-Olympic," 2010) to A$ 1.5 billion per annum ("Sports Medicine Australia, Olympic Gold and Australia's Economy Harmed by Injuries, Media Release," 2008). Lower extremity injury across a variety of sports range from 40% to 87% (Table 3.1). Five of the studies reported injury as a physical complaint, without confirming a *time loss event* due to injury. The range of lower extremity injury defined this way, compared to other body injury, was 40% in a ten year longitudinal study of injury among 16 professional Australian Rules football teams (Orchard & Seward, 2002) to 82% (Taunton, et al., 2003) who assessed recreational runners over a 13 week period. Using time loss as an injury definition, the lowest incidence of injury was a study of amateur rugby union involving six teams for one season (Babic, Misigoj-Durakovic, Matasic, & Jancic, 2001). The study reporting the highest incidence of lower extremity injury (87%) involved a five year analysis of a European football league of more than 1500 participants. Table 3.1 highlights a wide range of studies involving different codes of football and running, professional and amateur sport. Regardless of the injury definition, the incidence of lower extremity injury was high, providing further evidence for lower extremity injury based research.

Table 3.1 *Incidence of lower extremity musculoskeletal injury*

Authors	**Taunton et al**	**Brooks et al**	**Walden et al**	**Kinchington**	**Junge et al**	**Orchard**	**Babic et al**	**Orchard et al**	**Hagglund**
Year	2003	2005	2005	2001	2004	2004	2001	2007	2008
Sport	Running	England Rugby World Cup squad 2003	UEFA Champions League	Olympic Games 2000	FIFA World Cup 2002	National Rugby League	Amateur Rugby Union	Australian Football League	Football Swedish League
Incidence of lower extremity injury	82%	60%	50%	76%	53%	62%	48%	40%	87%
Details	13 weeks 844 runners prospectively followed	2 seasons 63 footballers; prospective injury surveillance	2 seasons 11 clubs, five European countries	Measure of medical encounters (>1100) which presented to the podiatry facility of the polyclinic	64 football matches	6 seasons two teams	1 season six teams	10 seasons (1997-2007); 16 teams	5 seasons Swedish football teams (>1500 subjects)

Authors	Taunton et al	Brooks et al	Walden et al	Kinchington	Junge et al	Orchard	Babic et al	Orchard et al	Hagglund
Injury	1	2	2	1	1	2	2	1	2

1= A physical complaint which medical attention was received regardless of consequences in respect to missed session.

2= A physical complaint which medical attention was received resulting in a time loss injury.

Abbreviations: FIFA, Fédération Internationale de Football Association; UEFA, Union of European Football Associations.

3.4.1.2.2 Studies of the comfort paradigm which permeate field of medicine.

The themes pertaining to comfort derived from the literature included the role of shoe comfort, comfort as a measure of well being, and reliability-validity studies (Table 3.2). The majority of comfort studies in the Table 3.2 are work place related including the nursing profession and military. Footwear comfort studies have also been performed (Au & Goonetilleke, 2007; Mundermann, et al., 2001) highlighting the importance of footwear as a variable for lower extremity studies of function and injury. However, no studies involved footwear comfort in sport despite the fact that the majority of weight bearing sports use footwear. Relevant footwear studies for sport generally involved laboratory based studies or friction-traction studies. The studies presented in Table 3.2, establish comfort as an important construct to general wellbeing and thus, applicable to the sporting environment.

Table 3.2 Comfort themes established in the literature

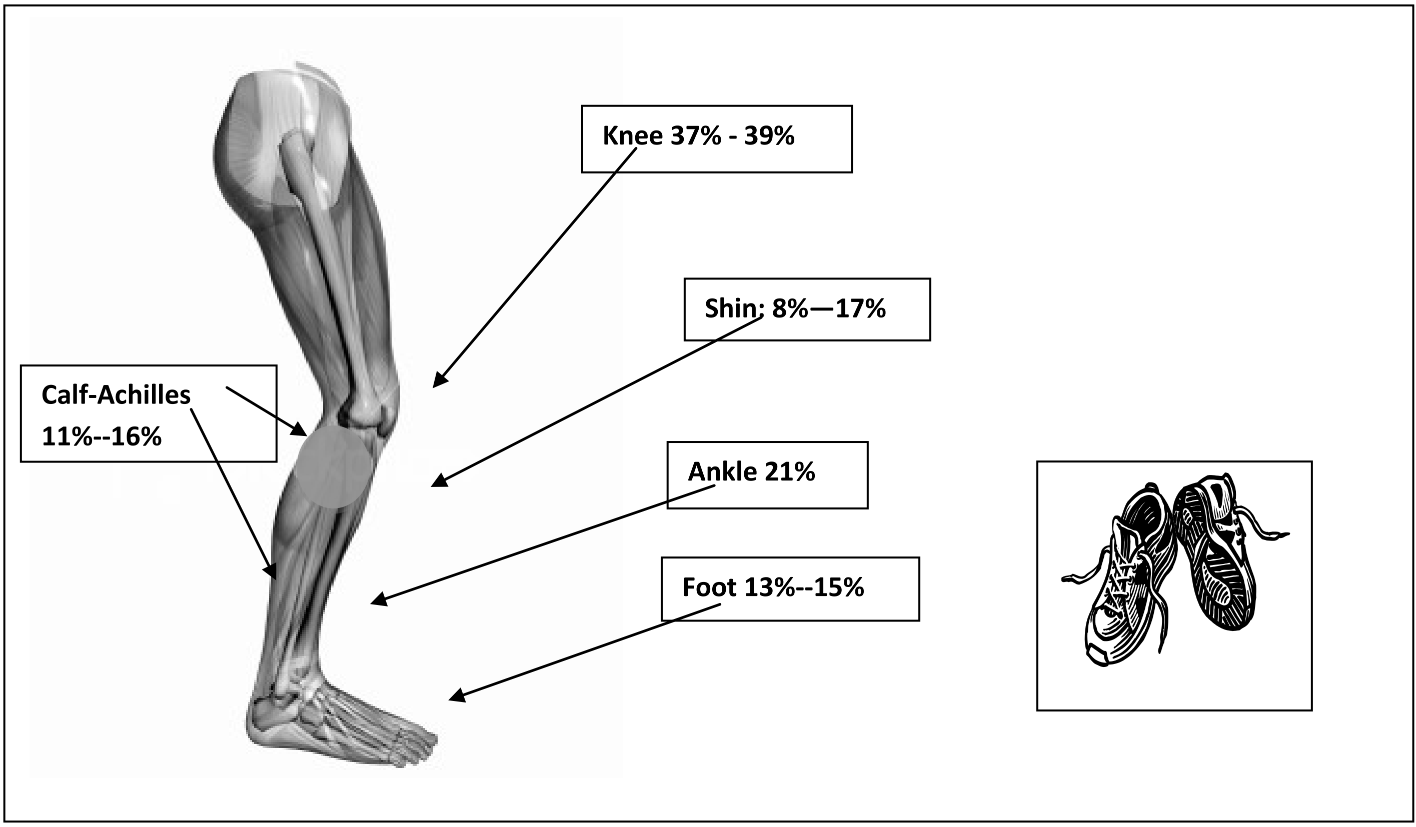
Themes	Population	Author
Shoe construction & comfort	+ Nursing profession	+ Chiu & Wang (2007)
	+ Females (fashion footwear)	+ Au & Goonetilleke (2007)
		+ Hong & Lee (2005)
	+ Military	+ Mundermann et al. (2001)
Anthropometry & comfort	+ Laboratory	+ Milani et al. (1997)
Injury & comfort	+ Military	+ Miller et al. (2000)
	+ Military	+ Mundermann et al. (2001)
Reliable method to measure shoe comfort	+ Laboratory	+ Mundermann et al. (2001)
Validation of a comfort measurement instrument	+ Hospital	+ Kolcaba & Steiner (2000)

Table 3.2 shows comfort themes have been researched in diverse environments. While instruments exist to estimate physical activity and recovery [rate of perceived exertion (RPE), training function score (TFS)], no such instrument is available to monitor lower extremity musculoskeletal wellbeing in sport. Where examples do exist for subjective comfort (Orlando & King, 2004), generally measures of lower extremity comfort are confined to one anatomical region. Examples of studies which have isolated one area include industrial footwear comfort (Chiu & Wang, 2007), work environment ground surface comfort, (Cham & Redfern, 2001) plantar pressures with sport shoes (Orendurff, et al., 2008), insole-orthotic comfort (Che, et al., 1994; Mundermann, et al., 2003b), fashion shoe comfort (Au & Goonetilleke (2007), skeletal alignment and footwear comfort (Miller, et al., 2000) and hybrid comfort studies examining the effect of footwear materials and inserts (Lake & Lafortune, 1998; Stefanyshyn & Nigg, 2000; Wakeling, Pascual, & Nigg, 2002). The only field based study investigated the role of insert-shoe comfort and the effect on injury (Slater, 1985). It could therefore be argued that without a measure of multiple anatomical sites, an incomplete description of comfort to the lower extremities exists. Single anatomy sites studies do not recognise the interaction of the anatomical linkage and the effect of body compensations.

3.4.1.3 Anatomical segments for comfort index inclusion

The literature indicates lower extremity injury inclusive of the foot, ankle, calf-Achilles, shin and knee account for the vast majority of all injury (Figure 3.1 and Table 3.1). The inclusion of footwear as an anatomical segment was considered valuable as it is regularly used as protective apparel in the majority of weight bearing sports. There is also much speculation that footwear plays a role in injury (Lake, 2000; McPoil, 2000; Yeung & Yeung, 2003) and comfort (Mundermann, et al., 2001).

Figure 3.1 Lower extremity injury incidence derived from the literature. Sources include Taunton et al. (2003), Guten (1997), Orchard & Seward (2008).



3.4.2 Stage two: developmental stage

Following assessments of various feedback scales purported in the health literature, a seven point Likert scale 0-6 was considered the most applicable to the professional sporting environment. An instrument to monitor lower extremity comfort was developed with anchors and signposts at all comfort scores (Figures

3.2 and 3.3). Because comfort is a positive feature, the scale was reversed with 0$^{\text{comfort points}}$ being the least and 6$^{\text{comfort points}}$ the most comfortable score.

The age of participants was mean 22.7 years; range 18-28 years). Six rookies (first year players), six footballers with experience (3 to 5 years) and eight senior-leadership players (> 5 years football experience) were recruited for the developmental stage. Three versions of the LLCI (LLCI^{1} LLCI^{2} LLCI^{3}) were trialled before the LLCI^{3} was considered ready for pilot evaluation (Stage 3).

3.4.2.1 Lower limb comfort index 1 (LLCI^{1})

Data were collected for six weeks (120 data sets). Each respondent was interviewed in a casual environment at weeks two, four and six (60 responses; Table 3.3) to provide feedback on: (i) interpretation of the LLCI, (ii) assess usability, (iii) obtain feedback on the appropriateness of the anatomical segments measured and (iv) anchors / signposts.

Feedback from LLCI^{1} (Table 3.3) indicated high agreement for overall *suitability* of the comfort index (82%) and *sign post suitability* (83%). *Ease of use* for completing the comfort index was < 50% agreement. The low agreement for the cohort for *ease of use* involved confusion regarding Achilles comfort. Some placed the Achilles condition in the calf tag, while others used the ankle (due to close proximity to the Achilles). Approximately half (51%) of respondents reported ambivalence or disagreed with the ease of using the index. The LLCI^{1} had two descriptor sets; one for anatomical segments, and a second for footwear, making interpretation of the comfort index more complex. The footwear descriptor set was subsequently deleted and footwear as a region of measurement was added to the anatomical descriptor set.

3.4.2.2 Lower limb comfort index 2 (LLCI ^{2})

The second version of the comfort index (LLCI ^{2}) was implemented for six weeks (120 data sets) and differed from LLCI ^{1} in two ways. The descriptive signposts and anchors for the footwear condition were removed to leave one descriptor set for both anatomical segmental comfort and footwear comfort. The footwear condition was treated as a component of anatomical segmental comfort (shoe, foot, ankle, calf-Achilles, shin, knee). The calf anatomical tag was expanded to include Achilles comfort (calf-Achilles). LLCI ^{2} was changed to reflect the feedback as outlined in methods. McNemar's test of agreement indicated that *suitability* of the comfort index and signposts remained high (>80%). *Ease of use* increased to 70% and *anatomical descriptor suitability* increased to 95%, due to the use of one descriptor for all segments. Feedback from interviews with the senior-leadership group of players indicated that some of the sign posts, specifically the descriptors for comfort scores 1, 2, 4, and 5 could be removed to improve ease of using the index.

3.4.2.3 Lower limb comfort index 3 (LLCI ^{3})

The LLCI with further modification (LLCI ^{3}) was implemented for six weeks (120 data sets). It differed from LLCI ^{2} by using two anchors and one central signpost. All respondents were re-interviewed to give a total of 60 responses over the six week period (Table 3.3). Agreement among the respondents meant no further refinements to the LLCI were required.

The final scale comprised a scoring system of $0^{\text{comfort points}}$ to $6^{\text{comfort points}}$ with anchors at extremities ($0^{\text{comfort points}}$ = extremely uncomfortable [unable to run or jump] and $6^{\text{comfort points}}$ = zero discomfort [best ever feel]). A midpoint signpost of $3^{\text{comfort points}}$ was designated a neutral position; $0^{\text{comfort points}}$ to $2^{\text{comfort points}}$ delineated uncomfortable and $4^{\text{comfort points}}$ to $6^{\text{comfort points}}$ comfortable (Figure 3.1).

The LLCI [3] indicated high agreement for *suitability* (90%), *ease of use* (95%), *anatomical descriptor* agreement (95%), and *signpost suitability* (88%) calculated from McNemar's test of agreement. The results indicated no requirement for further refinement of the LLCI. The final index was a seven point Likert scale which measured six areas pertinent to the lower extremity. The sign posts had scores $0^{\text{comfort points}}$ to $6^{\text{comfort points}}$ with two anchors and one central signpost. The final version was considered appropriate for reliability evaluation among a larger cohort.

Figure 3.2 *Lower Limb Comfort Index in the developmental stage*

<table>
<tr><td>Name:</td><td colspan="6">Place a score 0 to 6 in each box</td><td></td></tr>
<tr><td rowspan="2">Lower Extremity Comfort:

Rank each body area from 0-6 using the comfort descriptors</td><td>Foot</td><td>Ankle</td><td>Calf-
*Achilles</td><td>Shin</td><td>Knee</td><td>Footwear
**</td><td>Sum Comfort</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td>/36 maximum score</td></tr>
<tr><td colspan="7">COMFORT DESCRIPTORS

0 = extremely uncomfortable (unable to run or jump)

1= very uncomfortable *** (strongly affecting my running or training or performance)

2 = uncomfortable *** (somewhat affecting my running or training or performance)

3= neither uncomfortable or comfortable (neutral)

4= fairly comfortable *** (mild niggles but generally running & training well)

5= very comfortable *** (not affecting my running or training or performance)

6= zero discomfort (extremely comfortable; best ever feel)</td><td></td></tr>
</table>

**Achilles tag added for LLCI [2].*

*** Footwear descriptor set removed for LLCI [2]*

**** Comfort descriptors 1, 2, 4, & 5 removed for LLCI [3]*

Figure 3.3 *Final Lower Limb Comfort Index (LLCI [3])*

Name:	**Place a score 0 to 6 in each box**						
Lower extremity Comfort:	**Foot**	**Ankle**	**Calf-Achilles**	**Shin**	**Knee**	**Footwear**	**Sum Comfort**
Rank each body area from 0-6 using the ***comfort descriptors***							**/36 maximum score**
COMFORT DESCRIPTORS** **0 = extremely uncomfortable** (unable to run or jump) **1** **2** **3= neither uncomfortable or comfortable** (neutral) **4** **5** **6= zero discomfort** (extremely comfortable; best ever feel)							

*** included a partially anchored numeric rating scale with fixed anchor points at key positions on the scale. Descriptive explanations were condensed to Comfort Scores 0, 3 and 6.*

Table 3.3 shows that the percent of players who agreed, were ambivalent or disagreed with each domain of the LLCI at each of the three time points analysed by McNemar's test of agreement. The number of players who agreed with s*uitability* of the comfort index increased across the time points (Time 1 to Time 3), with a significant increase from 82% (Time 1) to 90% (Time 3); P=0.02.

For *ease of use*, there was a significant increase in the numbers of players who agreed across all time points (P<0.0001) with the percent who agreed increasing from 48.3% (Time 1) to 70% (Time 2) and 95% (Time 3). This was considered due to the simplification of the comfort descriptor sets, eliminating descriptions at comfort scores 1, 2, 4 and 5. Similarly for *anatomical descriptor suitability"*, agreement improved between Time 1 (55%) and Times 2 and 3 (95%), P<0.0001. For *signpost suitability*, there was trend for the percent of players who agreed to increase only slightly across the three time points. The changes associated with a positive response between times points was not statistically significant.

Reasons for disagreement in each domain were mainly confined to Time 1 and Time 2 for feedback regarding the labelling of the LLCI. By Time 3, disagreement was not due to LLCI interpretation, but participants either being unavailable for data entry and one participant who dropped out of the study.

Table 3.3 *Respondent results for LLCI development with 60 responses for each domain*

Domain	**Response**	**Time 1 LLCI ++**	**Time 2 LLCI +++**	**Time 3 LLCI**	**P value Time 1 vs 2**	**P value Time 1 vs 3**	**P value Time 2 vs 3**
suitability	Agree	49 81.7%	51 85%	54 90%	0.54	0.12	0.02
	Ambivalent	10 16.7%	8 13%	3 5%			
	Disagree	1 1.7%	1 2 %	3 5%			
ease of use	Agree	29 48.3%	42 70%	57 95%	0.003	<0.0001*	<0.0001*
	Ambivalent	11 18.3%	12 20%	0 0%			
	Disagree	20 33.3%	6 10%	3 5%			

Domain	Response	Time 1 LLCI ++	Time 2 LLCI +++	Time 3 LLCI	P value Time 1 vs 2	P value Time 1 vs 3	P value Time 2 vs 3
anatomical descriptor suitability	Agree	33 55%	57 95%	57 95%	<0.0001	<0.0001*	1.0*
	Ambivalent	17 28.3%	2 3.3%	0 0%			
	Disagree	10 16.7%	1 1.7%	3 5%			
sign post suitability	Agree	50 83.3%	49 81.7%	53 88.3%	1.0*	0.45*	0.096
	Ambivalent	10 16.7%	10 16.7%	4 6.7%			
	Disagree	0 0%	1 1.7%	3 5%			

*+ P value estimated by McNemar's statistic for 3x3 table or * by McNemar's statistic for 2x2 table with ambivalent and disagree groups combined where one or more of the domains had a zero response.*

++ Participant feedback: create a comfort measure for Achilles. Two sets of descriptors (anatomical segments & footwear) were confusing.

+++ Creation of three comfort descriptors resulting in two anchors and a central signpost.

3.4.3 Stage three: pilot reliability of LLCI

Twenty footballers, mean (SD) 24.4 years (3.2), not used during the developmental stages of LLCI testing were recruited to field test the final version of the LLCI for reliability. Twelve players from rugby league and eight from Australian rules who were not familiar with the LLCI were recruited to test the index over three sessions.

Table 3.4 indicates a high proportion of agreement for all comparisons of the LLCI. For overall lower extremity comfort (Sum score), the lowest percentage agreement between 0^{hours} and 4^{hours}, in an environment where there were no interventions to effect comfort, was 80% for Session 2 (ICC 0.994). This was due to four participants having a difference in sum score. However, the differences between time points were only $1^{\text{comfort point}}$. For individual anatomical markers Kappa agreement range was 0.85 – 1.00 (Session 1), 0.72 - 1.00 (Session 2) and 0.92 - 1.00 (Session 3). Markers for knee and ankle showed the least agreement in Session 2 where more than two participants recorded differences for the two time periods. However, the differences were only $1^{\text{comfort point}}$. This effect is represented in Figure 3.3 in which the largest difference in agreement was 15% for the ankle and knee markers (Session 2). The narrow range for test-re-test percentage agreement of lower extremity sum score and respective anatomical markers for three test sessions indicates high repeatability for two time periods across three testing sessions. Mean differences (Table 3.4) indicated no differences for Sum scores.

Table 3.4 *Frequency of numbers in agreement for comparisons between 0 ^{hours} and 4 ^{hours} on three separate days in 20 participants. Numbers in table are absolute participant numbers.*

Comparison	Number in agreement	Number differing by 1 comfort point	Number differing by 2 comfort points	Percent in agreement	Mean difference (SD)	Measurement error	Kappa or *ICC
Session 1							
Sum score	17	2	1	85%	-0.10	0.77	*0.991
Boot	20	-	-	100%	0.00	0.00	1.00
Foot	20	-	-	100%	0.00	0.00	1.00
Ankle	20	-	-	100%	0.00	0.00	1.00
Calf	19	1	-	95%	0.05	0.31	0.92
Shin	18	2	-	90%	-0.10	0.43	0.85
Knee	19	1	-	95%	-0.05	0.22	0.93
Session 2							
Sum score	16	4	-	80%	-0.10	0.62	*0.994
Boot	19	1	-	95%	-0.05	0.31	0.92
Foot	20	-	-	100%	0.00	0.00	1.00
Ankle	17	3	-	85%	-0.05	0.55	0.75
Calf	20	0	-	100%	0.00	0.00	1.00
Shin	18	2	-	90%	-0.10	0.43	0.82
Knee	16	4	-	80%	0.10	0.62	0.72
Session 3							
Sum score	18	2	-	90%	0.00	0.45	*0.996
Boot	19	1	-	95%	-0.05	0.31	0.92
Foot	20	-	-	100%	0.00	0.00	1.00
Ankle	20	-	-	100%	0.00	0.00	1.00
Calf	20	-	-	100%	0.00	0.00	1.00
Shin	19	1	-	95%	-0.05	0.31	0.92
Knee	19	-	1	95%	0.10	0.62	0.95

Figures 3.4 and 3.5, 3.6, and 3.7 illustrate the lack of difference for each anatomical marker and narrow 95%CI which confirms the reliability of the LLCI.

Figure 3.4 *Percentage agreements between lower extremity sum scores and individual anatomical markers for three testing sessions.*

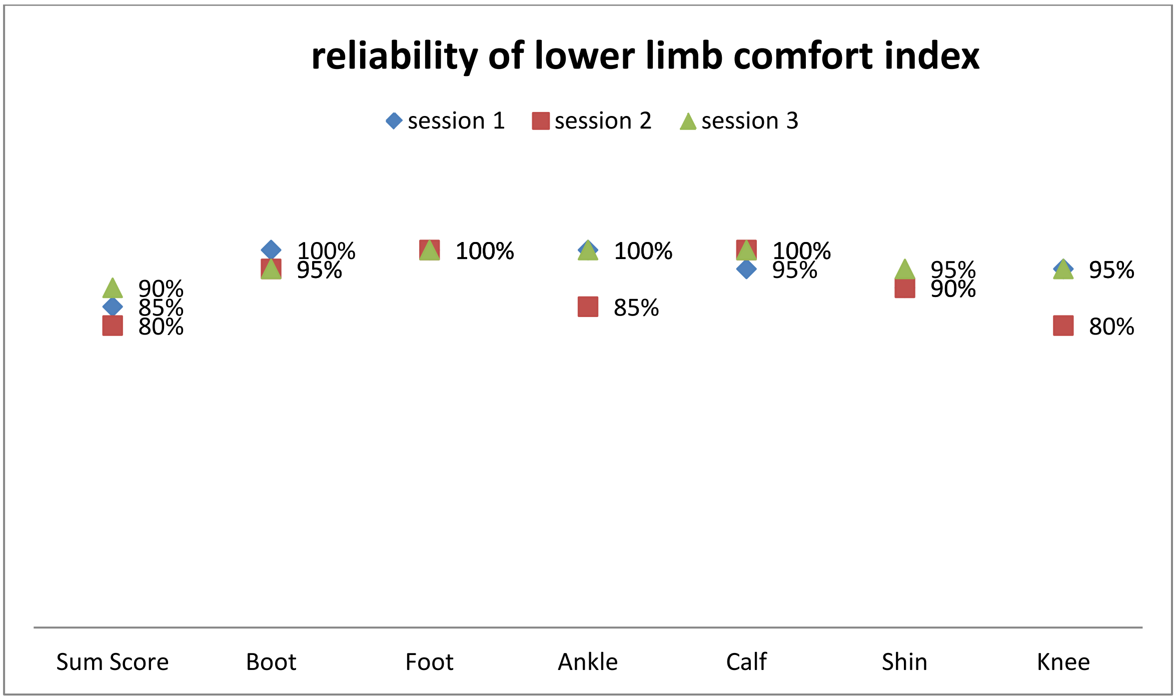


Figure 3.5 *Mean difference (95% CI) for test session one*

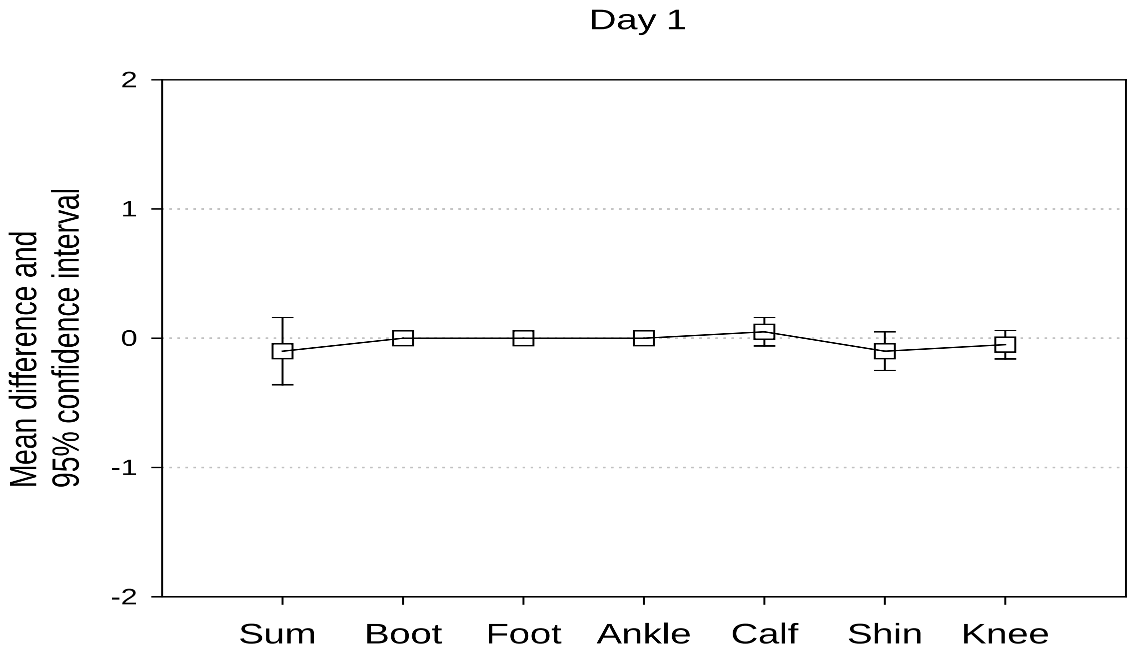


Figure 3.6 *Mean difference (95% CI) for test session two*

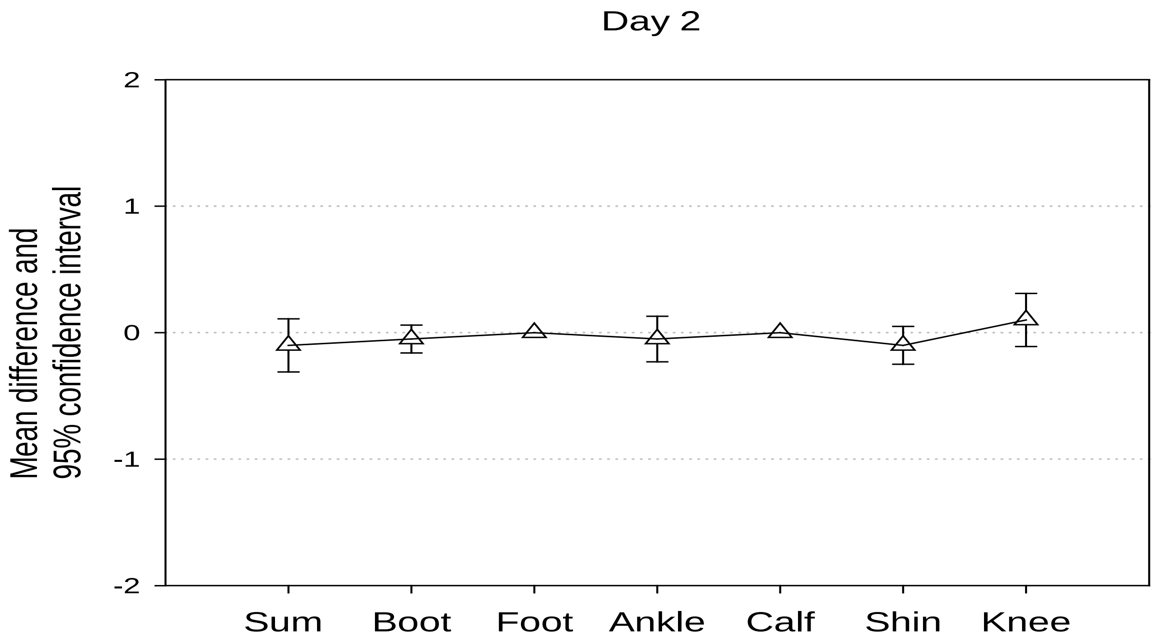
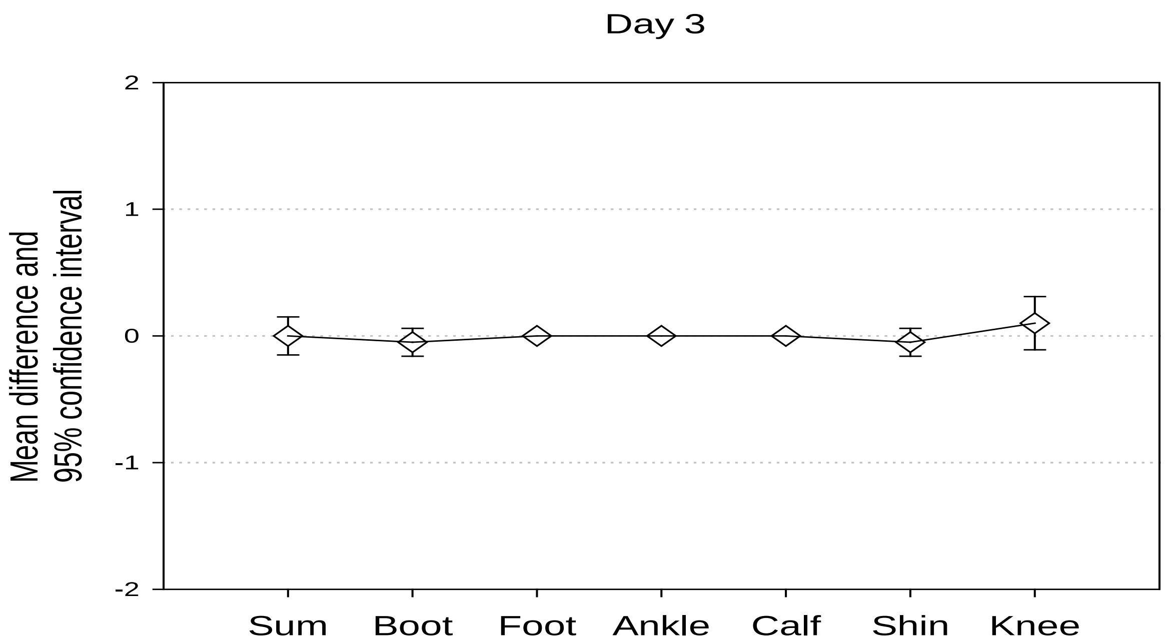


Figure 3.7 *Mean difference (95% CI) for test session three*



3.5 DISCUSSION

Few techniques are available within the sports injury environment to gather prospective data on lower extremity musculoskeletal comfort. An investigation of the literature indicated that development of an instrument had theoretical merit and had the potential to be feasible. Development was therefore based on stage one of a three phase project. Stage one involved a critical appraisal of available evidence showing:

I. The high incidence of lower extremity injury ranging from 40%-87% (Table 3.1) and prevalence of injury at key anatomical segments (Figure 3.1) for many sports including three codes of elite football.

II. The comfort paradigm which permeates areas of biomechanics, footwear, military medicine and hospital-nursing outcomes (Table 3.2), but has not been evaluated as an instrument of detection in sports medicine.

Professional footballers have many time restraints placed upon their daily activities, so the LLCI had to be deemed worthwhile to those completing the task and be completed swiftly. An important criterion for both respondent and evaluator of the data is the ability of the format not to be time consuming, well laid out, easy to understand, and completed with minimal evaluation. Therefore stage two and three of the study encompassed designing the LLCI and pilot testing in a controlled environment for use in football.

The adoption of a seven point Likert scale which was considered the most appropriate method of measurement for a professional sporting environment was due to ease of administration, clarity in responding, and general ease of interpretation to both the respondent and the evaluator. To ensure the comfort index was applicable to all footballers, recruitment of players with varying years of football experience participated in testing the anchor words, the ease and adaptability of the LLCI until the index was considered viable for pilot testing (stage three). The opinions of senior players provided valuable feedback on the LLCI during the development stage (Table 3.3) offering practical and frank opinions about suitability, benefit and time constraints of the LLCI. The inclusion of opinions from younger and mid-tier players provided a balanced response to ensure the index was agreeable to a wide range of players. Population specific instruments for football codes have been successfully used for injury surveillance (Collie, et al., 2003; Orchard, 2004).

Overall compliance during the development stage of the LLCI was high. Less than 5% of participants did not complete the LLCI during any given week. The overall consensus was the index was easy to understand, did not impose time constraints (took less than 60 seconds to complete), and respondents considered the format to be of benefit (Table 3.3). Perceived benefits include; (i) itemising anatomical segmental wellbeing and overall lower extremity comfort, (ii) benchmarking individual player comfort for football preparation (training and rehabilitation when injured), (iii) providing a comfort reference point for participants to quantify future discomfort events, (iv) providing a method of measuring wellbeing of an individual.

During the developmental stages modifications were made to the LLCI. Areas of the LLCI requiring adjustment to the index revolved around confusion and ambiguity regarding the comfort descriptors and anatomical tags. Respondents identified confusion regarding the footwear tag due to a second descriptor set which was dedicated to footwear. During the six week trial of LLCI [1], 45% of respondents failed to enter a footwear response without prompting from the researcher. Reasons expressed by respondents included *"did not see 2nd set of descriptors"*, or *"too much information to read with a second set of descriptions dedicated to the footwear condition".* The descriptor set for LLCI [2] incorporated the footwear tag. Subsequently respondent agreement to *ease of use* and *anatomical descriptor suitability"* increased to 70% and 95% respectively.

Ambiguity was noted by some respondents for calf and ankle comfort. This was attributed to participants having two similar anatomical markers to record Achilles discomfort. The anatomy of the Achilles tendon approximates both the calf and the ankle. During the development phase of the LLCI, the following scenarios occurred: (i) Achilles discomfort was duplicated by recording low comfort at two anatomical regions (ankle and calf); (ii) Achilles discomfort was recorded inadvertently affecting ankle or calf comfort scores; (iii) Achilles discomfort was not recorded at all as there was no obvious anatomical tag to describe the Achilles. The index was adjusted for LLCI [2] by the inclusion of an Achilles tag associated with the calf.

To improve the ease and suitability of the signposts, amendments were made to the comfort descriptor legend for LLCI [3.] The descriptors at points 1-2 and 4-5 were considered redundant. The use of anchors (0 **comfort points** = extremely uncomfortable; unable to run or jump and 6 **comfort points** = zero discomfort, best ever feel) provided two extremes of stimuli commonly used when anchoring subjective feedback scales. A central signpost denoted scores either side of a central position and provides respondents a clear delineation between comfort and discomfort (Redmond, Crosbie, & Ouvrier, 2006). As a consequence, overall agreement rose to 90% (*suitability*), 95% (*ease of use*), and 88% (*sign post suitability*). Although speculative, the increase in disagreement from 1.7% to 5% for *sign post suitability* was most likely due to a decreased sample size during LLCI [3] that artificially inflated reports of relative error.

Other reasons for improvement in the statistical results for agreement may have involved familiarity with using the LLCI. The participants used the index over an 18 week period. Repeated task oriented events will result in a participant's skill acquisition improving from a novice status to one of expert as a task is learned (Benner, 1982; English, 1993). While such a theory may apply to the domain *ease of use* and *sign post suitability* high levels of agreement would not be expected for overall *suitability* or the *anatomical descriptor* segments measured if the index was not considered appropriate.

Good agreement for all facets of LLCI reliability indicated good face reliability for the LLCI. The use of multiple markers (foot, ankle, calf-Achilles, shin, knee and footwear) to assess lower extremity comfort affects overall LLCI sensitivity to change compared with an instrument with fewer markers. This ensured a more clinically relevant instrument that provided a complete overview of lower extremity wellbeing, as well as appraisal of individual anatomical segments. The use of multiple markers provides rigorous testing of reliability as six markers measured repeatedly will significantly affect the overall sum score reliability.

The measurement errors (Table 3.4) show the participants true comfort will lay within one point of baseline comfort on most occasions for the majority of markers measured. The chance for memory recall bias was limited by randomising the order for scoring the anatomical markers between the two time periods and for the three testing sessions. Therefore, the repeatability in scores between the two testing periods were considered valid scores and not due to recall bias.

Differences in agreement for lower extremity comfort over a short time period (0^{hours} and 4^{hours}) will unlikely be attributed to a change in comfort if the testing environment remains constant. The testing period remained stable, i.e. no change to the testing environment such as physical exertion or musculoskeletal rehabilitation occurred. Anticipated reasons for differences in agreement will be due to: (i) inability of an individual to self-assess comfort accurately due to conceptual matters, (ii) difficulty comprehending the tool used to measure comfort, (iii) true change in comfort.

The LLCI showed good repeatability and minimal differences in agreement. The range of scores varied less than $1^{\text{comfort point}}$ for all marker measures, except for one occasion. Therefore, the small differences in agreement provide confidence that the variability in scores is not due to conceptual inability of participants to assess comfort, nor an inability to comprehend the index. The observed differences may be due to judgement error by participants, which lies within an acceptable range and so not affect reliability. The results also contribute to face validity as Table 3.3 indicates *ease of use* (95%; $P<0.001$) and *suitability* of the LLCI (90%; $P<0.02$) was high. The small differences in agreement attest these results.

Face reliability can be assessed by the conditions in which the testing occurred. Unlike, laboratory or controlled clinical research in which full participant attention can be applied to the task at hand; football environments contain many distractions including impromptu meetings, non-scheduled rehabilitation sessions and multiple other priorities and interruptions from football related matters. Often research-related events involving professional footballers are an additional task for participants. Therefore, the ability for 20 participants to complete the LLCI over a three session testing period with the distractions of the competing environment provided further confidence the LLCI is an instrument that can be effectively applied in many different environments.

3.6 CONCLUSIONS

The importance of comfort as a means to aid health and wellbeing is recognised as a viable method of assessing pain and discomfort. However such strategies appear infrequently in the sporting environment. The use of multiple anatomical markers to derive an overall lower extremity comfort score presents a new method of measuring lower extremity wellbeing. The development and implementation of the LLCI in the professional football environment was reliable in a semi-controlled environment. The developed LLCI showed good trait construct and provides confidence to investigate the LLCI in a future study (Chapter 4) for inter-rater consistency in a wider cohort of professional footballers under different conditions such as Match-day and training week environments.

CHAPTER FOUR

RELIABILITY OF AN INSTRUMENT TO DETERMINE LOWER LIMB COMFORT IN PROFESSIONAL FOOTBALL

This chapter is supported by the publication:

Kinchington, M., Ball, K., Naughton, G. (2010). Reliability of an instrument to determine lower limb comfort in professional football. Open Access Journal of Sports Medicine, Volume 2010, 1, 77-85.

4.1 ABSTRACT

Background: This study extends the development of the LLCI (Chapter 3) and further explores the field of injury awareness in professional football by implementing the LLCI in a competitive football environment.

Objectives: Examine the reliability of the LLCI to measure lower extremity comfort and assess whether LLCI measurements were responsive to changes in lower limb comfort over time.

Methods: Participants from two codes of professional football (rugby league and Australian rules) were recruited. Twenty-two players were recruited for a test session following a football match and a separate testing session involved 41 players at the beginning of the football-training week. Mean differences, standard deviation (SD) and intra-class correlation coefficient (ICC) for repeated comfort ratings for all individuals were used to calculate reliability. To test responsiveness, mean (SD) comfort scores were calculated and plotted to investigate how comfort scores varied with time. Repeated measures analysis of variance was used to assess the within-player significance of differences in lower limb comfort.

Results: The reliability of the LLCI was observed in two professional football environments; Weekday training (mean difference 0.1 point, ICC 0.99) and Match-day (mean difference 0.2 points, ICC 0.97). Measurements of lower extremity comfort were responsive to changes in comfort over time. Within player differences were not significant for periods 0^{hours} and 8^{hours} ($P>0.05$), significant for time periods 0^{hours} to 24^{hours} ($P<0.05$) and highly significant between 24^{hours} and 96^{hours} ($P<0.01$).

Conclusions: The LLCI when used in a competitive football environment was both reliable and responsive to change during both a football training week and under Match-day conditions. This novel instrument to measure lower extremity comfort provides a tool for clinicians and athletes which was easy to implement, providing prospective data on aspects of lower extremity well-being.

4.2 INTRODUCTION

Lower extremity injury reduction is an important consideration in professional football for numerous reasons ranging from performance-based criteria (player welfare, football skills, team cohesion, winning games) to financial reasons such as player payments, medical rehabilitation costs, and club sponsorship based upon team success (Engebretsen & Bahr, 2005; Luthje, 1996). Injury statistics across a variety of running-based team sports (the rugby codes, football, Australian rules, and American football) indicate that the majority of injuries sustained occur in lower limbs. Lower extremity injury (knee, shin, calf, foot and ankle) in the Australian Football League over ten years accounted for 40% of all injury (Orchard & Seward, 2008) with 46% for rugby league data assessed over five years (Gissane, Jennings, Kerr, & White, 2002), 87% for football (soccer) over five seasons (Martin Hagglund, et al., 2007) and 54% for five seasons of high school American Football (Meyers & Barnhill, 2004).

The cost of football injuries is significant both in terms of financial considerations (Dvorak & Junge, 2000; McManus, et al., 2004; Orchard & Seward, 2008), individual player considerations (Luthje, 1996) and retirement welfare (Bahr & Krosshaug, 2005). Therefore, injury outcomes, injury prevention and intervention methods in all codes of football has become an increasingly important focal point for researchers and clinicians (Arnason, et al., 2004; Drawer & Fuller, 2002; Dvorak, et al., 2000; Murphy, Connolly, & Beynnon, 2003; Norton, Schwerdt, & Lange, 2001; Wong & Hong, 2005).

An inherent difficulty in assessing lower extremity injury risk factors in football is the complex, multi-factorial nature of injury which includes both extrinsic (environmental, ground surfaces, training methods etc) and intrinsic (foot kinematics, foot-lower limb morphology, footwear) factors (Arnason, et al., 2004; Dvorak & Junge, 2000; Neely, 1998; Williams, McClay, & Hamill, 2001). Injury in its simplest form can be classified as contact and non-contact. Contact injuries are an accepted part of football and considered non modifiable within the boundaries of fair play and use of protective equipment (e.g. shin guards). Non-contact injuries are speculated to be modifiable with prevention programs. Examples of preventative measures include programs such as TRIPP (Finch, 2006), screening and identification of anatomical risk factors (Dennis, Finch, McIntosh, & Elliott, 2008; A. Miller & Callister, 2009), prescriptive footwear (Kinchington, 2003; Mundermann, et al., 2001), and proprioception drills, balance, agility, strength, and practicing of skills (Bahr & Krosshaug, 2005). An integral part of injury management is the identification of risk factors that predispose an individual to injury (Krosshaug, Andersen, Olsen, Myklebust, & Bahr, 2005). However, because injuries are multifactorial, the inherent difficult faced by researchers and clinicians is the vast number of risk factors which need to be measured. Therefore, many studies have been limited to the measurement of one or two isolated factors. For example, while the literature supports a strong scientific association between lower extremity injury and foot kinematics (Huson, 2000; Nester, Van Der Linden, & Bowker, 2003; Nigg, et al., 1999; Reinschmidt, Van den Bogert, Nigg, Lundberg, & Murphy, 1997; Stagni, Leardini, O'Connor, & Giannini, 2003), there is little consensus between health professionals about the intrinsic aetiology of lower extremity injury.

An alternate approach to injury management is the prospective measurement of lower extremity comfort which provides a barometer to the health and well-being status of the lower limb (Chapters 5, 6, 7). Regardless of the cause or mechanism of injury, the endpoint is the same in that it is expressed as pain and discomfort. When one area of the body is distressed (pain, discomfort, or injury) pain inhibition responses and musculoskeletal compensations occur not only at the site of injury but also at adjacent anatomical structures which may predispose other regions of the body to injury. Chapter 3 described the development of an instrument to monitor overall and segmental lower extremity comfort to enable the collection of prospective data which could be used to set benchmark comfort for individuals and therefore to monitor future lower extremity health, limb injury and the factors that affect it (Chapters 5, 6, and 7).

The impetus for the implementation the LLCI in the football environment evolved from:

I. The lack of a clinically relevant tool to assess prospective lower extremity health;
II. The high proportion of lower extremity musculoskeletal injuries reported in the literature;
III. Previous studies indicating good reliability and validity of limb comfort measures for various population groups (military, hospital, laboratory);
IV. The lack of an instrument to measure lower extremity comfort in a sporting environment;
V. The anticipated benefit of a lower extremity comfort measure for use in clinical and research settings.

In the developmental study (Chapter 3), the LLCI was trialled with professional footballers and had good face and construct validity to enable further testing in a wider football environment.

4.3 METHODS

Participants from an elite sporting environment comprising two codes of professional football (rugby league and Australian rules) were recruited to assess how repeatable the LLCI was over time and the extent to which it responded to changes in comfort. One testing session was implemented in 22 players following a football match and a separate testing session was implemented in 41 players at the beginning of the training week, approximately 36^{hours} to 48^{hours} post game. Comparisons were made between the time intervals for both Weekday and Match-day comfort to determine the reliability of the LLCI comfort scores under normal sporting conditions and the responsiveness of LLCI comfort scores to clinical changes in comfort.

To test the hypothesis that the LLCI was a reliable tool to record repeated measures of lower extremity comfort, the environment for players to record lower extremity comfort remained stable, without interventions which would contaminate reliability testing. To ascertain responsiveness of the LLCI, comfort measures were taken during a regular training week for professional football, when the test environment was constantly changing.

Data collection took place at Football Club premises in an environment consistent and familiar to the players. Therefore Match-day comfort was recorded at home game events only. Reserve or non-senior players were recruited as Match-day participants because these matches were scheduled earlier in the day, players did not have media or sponsor commitments, and had an obligation to be present at the main game to support other teammates in following matches.

Test conditions for Weekday and Match-day reliability testing of the LLCI involved players entering comfort measures using the format shown in Figure 4.1. Data for six anatomical segments (foot, ankle, calf-Achilles, shin, knee and football boot) were rated for comfort. The minimum score was $0^{\text{comfort points}}$ and the maximum score was $6^{\text{comfort points}}$ for each segment. An overall sum of the six anatomical segments was calculated to provide a maximum score of $36^{\text{comfort points}}$.

Figure 4.1 *Lower Limb Comfort Index shows a numeric rating scale with fixed anchor points at key positions on the scale. Visual descriptive explanations provide further interpretation of the anchors relevant to physical requirements participating in football.*

<table>
<tr><td>Name:</td><td colspan="6">Place a score 0 to 6 in each box</td><td></td></tr>
<tr><td rowspan="2">Lower extremity Comfort:
Rank each body area from 0-6 using the comfort descriptors</td><td>Foot</td><td>Ankle</td><td>Calf-Achilles</td><td>Shin</td><td>Knee</td><td>Footwear</td><td>Sum Comfort</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td>/36 maximum score</td></tr>
<tr><td colspan="7">COMFORT DESCRIPTORS
0 = extremely uncomfortable (unable to run or jump)
1
2
3= neither uncomfortable or comfortable (neutral)
4
5
6= zero discomfort (extremely comfortable; best ever feel)</td><td></td></tr>
</table>

For Weekday comfort, recordings of lower extremity comfort were entered for five weeks over a 20 week period. For each week, five measures of lower extremity comfort were collected and categorised according to change in the test environment (Table 4.1). Condition 1 represented the first measure that was recorded for Weekday comfort, 24-36 $^{\text{hours}}$ following Match-day. Condition 2 represented data collection +24 $^{\text{hours}}$ after Condition 1 and Condition 3 was +96 $^{\text{hours}}$ from Condition 1.

Repeatability was calculated during Condition1 where there was no change to the test environment. Changes in comfort were assessed in Condition 2 and 3 which were characterised by significant changes to the test environment. It was anticipated that each player would provide a maximum of 30 measures of comfort over five testing sessions, suitable for repeated measures analyses and to test for differences in comfort over time.

For Match-day comfort testing, the same format applied except the testing was performed over three test periods. Three comfort measures were taken over a 3^{hour} period. To test for repeatability of comfort scores, the data was collected in a stable environment where there was no physical or medical intervention. To ensure a stable test environment, the first set of comfort measures occurred 45^{minutes} to 60^{minutes} post match, once players had performed their Match-day cool down and rehabilitation (Table 4.1).

Table 4.1 *Time line for comfort data collection for Match-day and Weekday measures*

MATCH-DAY LLCI COMFORT SCORES	
Time of data collection	**Environment**
0 minutes to 60 minutes following match	Warm down, stretch, ice baths, hydration, and shower.
(no data collection)	
0 hours *(data collection 1)*	↑ No change to test environment in terms of medical, rehabilitation or training intervention. Player rest, relax, eat. ↓
+90 minutes *(data collection 2)*	
+3 hours *(data collection 3)*	

Table 4.1 (continued)

WEEKDAY- LLCI COMFORT SCORES

Time of data collection	**Environment**
Condition 1 (+ 36 hours to 48 hours post match) 0 hours *(data collection 1)*	Changes to test environment between Match-day and Weekday include recovery training, massage and medical intervention.
+4 hours *(data collection 2)*	No change to test environment 0 hours to 4 hours in terms of physical, training, or medical intervention. Activities for the day include investigation of any medical needs, team and coach meetings and club events.
+8 hours *(data collection 3)*	No change to test environment 0 hours to 8 hours in terms of physical, training, or medical intervention.
Condition 2 +24 hours from Condition 1	Changes to the environment include sleep, massage, yoga, reduction in muscle soreness.
Condition 3 + 96 hours from Condition 1	Full week of physical training, rehabilitation, medical intervention.

4.3.1 Weekday and match-day statistical analysis

Reliability testing included calculating mean differences with standard deviation (SD) for Weekday comfort (time zone 0 ^{hours} to +8 ^{hours}) and post Match-day comfort, 0 ^{hours} to +3 ^{hours} (Table 4.2) for each week for players who provided data for both conditions. Measurement error was calculated from the standard deviation of the differences using the methods of Bland & Altman (1996). The measurement error indicates a range above and below any reported value in which we can be 95% certain that the 'true' value for a player lies. In addition, intra-class correlation coefficient (ICC) for repeated comfort ratings for all individuals and sessions was computed from one way analysis of variance using the method for fixed observers because players self-reported their comfort scores. Intraclass correlation coefficients have previously been used in comfort studies (Miller, et al., 2000; Mundermann, et al., 2001) and were calculated in this study for repeated comfort for two conditions; Weekday (0 ^{hours} and +8 ^{hours}) and Match-day (0 ^{hours} and +3 ^{hours}).

To test responsiveness, mean comfort scores with standard deviation (SD) were also calculated for both Weekday and Match-day conditions (Table 4.3). Mean comfort scores were plotted (Figures 4.2 & 4.3) for Weekdays and Match-days to investigate how comfort scores varied with time. General linear modelling (repeated measures analysis of variance) was used to assess the within-player significance of differences in lower extremity comfort (intra-week) for both Weekday (Table 4.4) and Match-day (Table 4.5) comfort. Planned post-hoc comparisons were computed using the least significant differences (LSD) method with mean differences and 95% confidence intervals (95% CI). The Huynh-Feldt

P-value was used to assess the effect of time across each model because not all models conformed to the requirement of sphericity.

4.4 RESULTS

The results indicate the LLCI was reliable when tested for repeated measures and how the index measures lower extremity comfort changes with time. Table 4.2 shows the reliability of the comfort scores for each week. Intraclass correlation coefficients for intra-test repeatability ranged between 0.994 and 0.999 for Weekday and 0.974 and 0.998 for Match-day conditions. The recording of lower extremity comfort to calculate ICC's occurred at 0 $^{\text{hours}}$ and +8 $^{\text{hours}}$ for the Weekday condition and 0 $^{\text{hours}}$ and 3 $^{\text{hours}}$ for Match-day. For both test conditions, the environment was stable, where there were no interventions to effect repeatability testings.

For Weekday results, the mean within player differences were either zero or very small at 0.1 in Week 2 indicating strong reliability. The measurement error indicates the range either side of a given measurement in which we can be 95% certain that the true value for a player lies. For Weeks 1, 3 and 4 the measurement error was less than 1 $^{\text{comfort point}}$ indicating excellent reliability. For Weeks 2 and 4, the measurement error was less than 1.5 points indicating very good reliability. The ICC which indicates the proportion of variance in within-player measurements that can be attributed to true differences between players was extremely high on all days. The ICC values of over 0.99 indicates that over 99% of the variance is due to true variation between players and less than 1% of the variance is due to measurement error in the LLCI.

For Match-day, the measurement error was small at 0.9 to 1.6 on Days 1, 2 and 4. On Day 3, the measurement error was larger at 2.5 with one player rating 3[comfort] points higher than their original score. The ICC values were high indicating that on Days 1, 2 and 4, over 99% of the variance was due to true variation between players and less than 1% due to measurement error. On Day 3, over 97% of the variance in the LLCI was due to true variation between players and less than 3% was due to measurement error

Table 4.2 *Weekday and Match-day mean differences and the intra-class correlation coefficient (ICC)*

	Week	**Number**	**Mean difference (SD)**	**Measurement error**	**ICC**
Weekday	1	40	0.0 (0.16)	0.43	0.999
	2	38	0.1 (0.46)	1.28	0.994
	3	39	0.0 (0.26)	0.73	0.999
	4	39	0.0 (0.49)	1.37	0.996
	5	39	0.0 (0.35)	0.96	0.998
Match-day	1	19	0.1 (0.33)	0.91	0.998
	2	18	-0.2 (0.45)	1.25	0.996
	3	19	0.1 (0.91)	2.53	0.974
	4	19	0.0 (0.57)	1.59	0.994

Table 4.3 show the mean (SD) comfort scores for Weekday and Match-day conditions. Weekday measures were taken at four time points over 24 $^{\text{hours}}$ and +96 $^{\text{hours}}$, for the five weeks of measurement. The mean values are plotted in Figure 4.2 and 4.3 respectively. For Weekday results, the mean scores remained fairly constant at 0 $^{\text{hours}}$, +4 $^{\text{hours}}$, +8 $^{\text{hours}}$ and +24 $^{\text{hours}}$ but increased at +96 $^{\text{hours}}$ in all weeks. The mean scores in Weeks 4 and 5 were approximately one point below the mean scores recorded in Weeks 1, 2 and 3 and indicated comfort variations between testing weeks.

For Match-day, there was little variation in mean scores at baseline, +90 $^{\text{minutes}}$ and +3 $^{\text{hours}}$ but a large increase in scores at +36 $^{\text{hours}}$. In Week 5 data was collected from only 9 participants and therefore these results were not used in the statistical analysis. However, the data was consistent with Weeks 1-4 highlighting no difference in mean sum comfort scores for time periods 0 $^{\text{hours}}$ and +90 $^{\text{minutes}}$ and larger differences between +3 $^{\text{hours}}$ and +36 $^{\text{hours}}$.

To test whether the differences in scores between time points were statistically significant, repeated measures ANOVA was used to examine within player differences. The results for Weekday and Match-day are shown in (Table 4.4 and 4.5).

Table 4.3 *Mean Weekday and Match-day comfort scores with standard deviation in brackets*

Weekday	**N**	**0** hours	**+4** hours	**+8** hours	**+24** hours	**+96** hours
Week 1	41	27.6 (3.4)	27.6 (3.4)	27.7 (3.4)	28.0 (3.4)	29.5 (3.2)
Week 2	35	27.4 (3.2)	27.4 (3.2)	27.5 (3.3)	27.7 (3.1)	29.1 (2.7)
Week 3	37	27.6 (4.6)	27.6 (4.6)	27.7 (4.5)	28.0 (4.3)	29.0 (4.3)
Week 4	38	26.6 (3.6)	26.6 (3.6)	26.7 (3.6)	26.8 (3.5)	28.1 (3.7)
Week 5	34	26.4 (4.2)	26.4 (4.1)	26.3 (4.2)	26.6 (4.8)	28.7 (4.3)

Match-day	**N**	**0** hours	**+90** minutes	**+3** hours	**+36** hours
Week 1	19	23.8 (3.8)	23.8 (3.8)	23.9 (3.9)	26.9 (3.8)
Week 2	18	23.3 (4.4)	23.3 (4.4)	23.1 (4.3)	25.9 (3.0)
Week 3	19	24.0 (3.0)	24.0 (3.0)	24.1 (2.8)	27.5 (3.6)
Week 4	19	24.1 (3.6)	24.1 (3.5)	24.1 (3.9)	27.3 (3.7)
Week 5	9	26.0 (4.2)	26.0 (4.2)	25.3 (4.7)	28.4 (4.6)

Figure 4.2 *Weekday mean comfort*

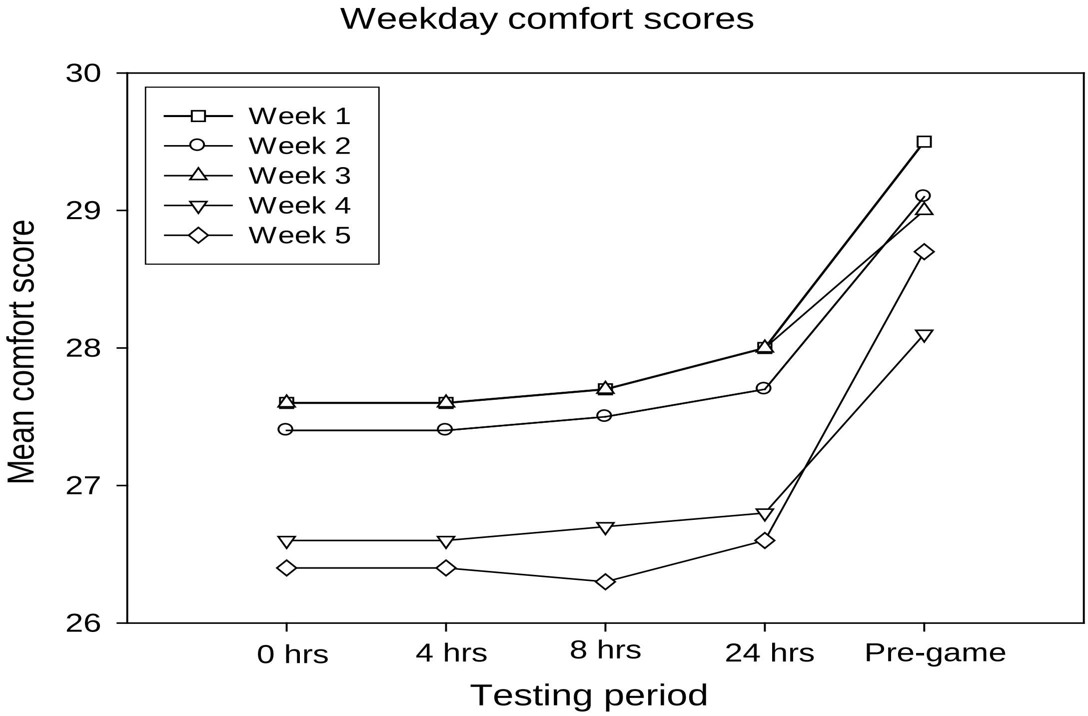


Figure 4.2 graphs the results tabulated for Weekday lower extremity comfort. For time zones 0^{hours}, $+4^{\text{hours}}$, and $+8^{\text{hours}}$ where the environment was stable there was no significant change in comfort scores, although Week 5 illustrates a reduction in comfort between $+4^{\text{hours}}$ and $+8^{\text{hours}}$. The reason for this was Week 5 was the only week where comfort dropped for this time period; however it was less than $0.5^{\text{comfort points}}$. When the environment changed, at $+24^{\text{hours}}$ and $+96^{\text{hours}}$ (pre-game), comfort changed significantly in an upward trend.

__Figure 4.3__ Match-day mean comfort

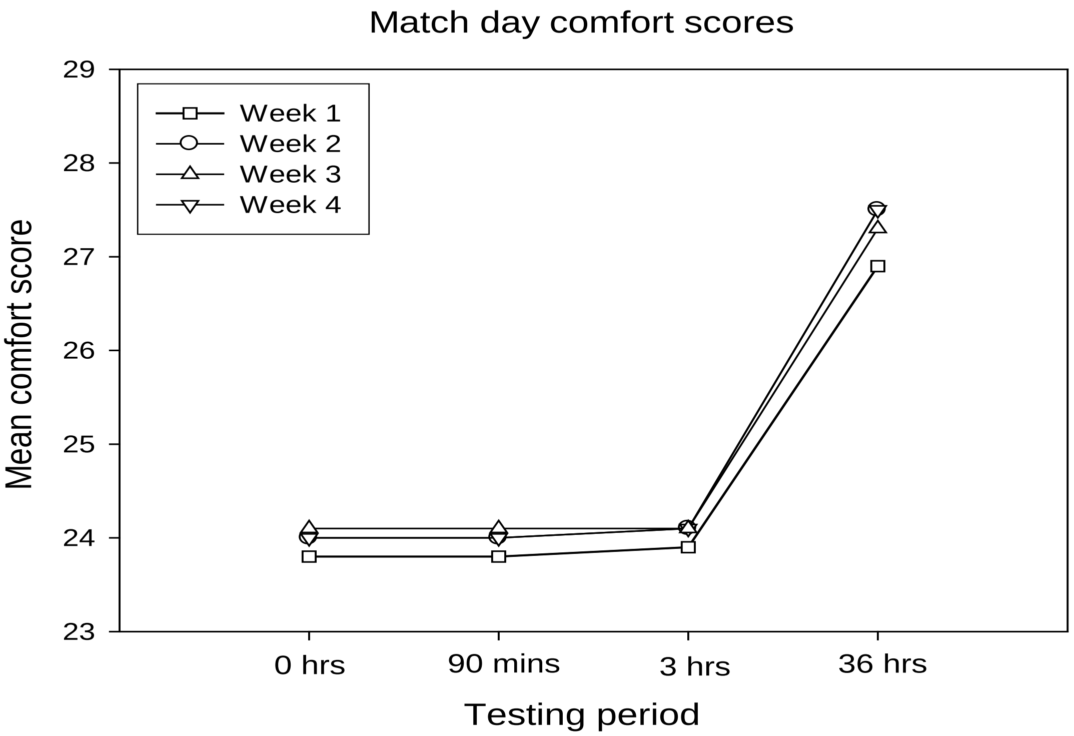


Figure 4.3 illustrates Match-day comfort. Zero hours represents the first collection of comfort. The data was captured a sufficient period following the match for the players to be in a relaxed state. Over a 3 hour period there was no significant change in musculoskeletal comfort. Significant changes to lower extremity comfort did not occur until +36 hours following +3 hours data collection, indicating with the passage of time, following physical exertion, comfort improves. This increase in comfort was the greatest change to comfort of all the time periods collected

A comparison between Figures 4.2 and 4.3 indicates the largest change in comfort occured +36 hours Match-day data collection, which was attributed to the high intensity demands placed upon the musculoskeletal system with professional football and how the body resets comfort with the passage of time when the physical exertion is removed. Further comparisons between Match-day and Weekday scores are indicated by the baseline scores where for all weeks lower extremity comfort was almost $2^{\text{comfort points}}$ less for Match-day scores than Weekday scores. This further highlights the magnitude of post match discomfort compared to other times when comfort is assessed during the week for professional Rugby League and Australian Rules players.

Table 4.4 shows there were no statistically significant differences in the scores recorded at time points 0^{hours}, $+4^{\text{hours}}$ and $+8^{\text{hours}}$. The absolute difference in mean scores between these time points was very small and varied from 0.00 to only 0.11. There were differences in scores between times points 0^{hours} and $+24^{\text{hours}}$. Although these differences were significant in Weeks 1, 2 and 4, the absolute difference in mean scores between 0^{hours} and $+24^{\text{hours}}$ varied between only 0.21 and 0.37 points.

The differences in scores between baseline and 24^{hours} were statistically significant for all weeks with mean within-player differences ranging from1.4 to 2.3 points. There were also large differences between $+24^{\text{hours}}$ and $+96^{\text{hours}}$ (pre-game). These differences, which ranged from 1.1 to 2.3 points, were all statistically significant.

Table 4.4 *Weekday within-player differences*

	Time zone	Participant Numbers	P value (Time)	Mean difference and 95%CI	P value for planned contrast
Week 1		41	<0.0001		
	0 hours vs 4 hours			0.0 (0.0, 0.0)	1.0
	0 hours vs 8 hours			-0.02 (-0.07, 0.03)	0.32
	0 hours vs 24 hours			-0.35 (-0.61, -0.10)	0.008
	0 hours vs 96 hours			-1.86 (-2.64, -1.07)	<0.0001
	4 hours vs 8 hours			-0.02 (-0.07, 0.02)	0.32
	24 hours vs 96 hours			-1.50 (-2.20, 0.80)	<0.0001
Week 2		35	0.001		
	0 hours vs 4 hours			0.0 (0.0, 0.0)	1.0
	0 hours vs 8 hours			0.11 (-0.05, 0.28)	0.17
	0 hours vs 24 hours			0.37 (0.03, 0.71)	0.03
	0 hours vs 96 hours			1.76 (0.74, 2.77))	0.001
	4 hours vs 8 hours			0.11 (-0.05, 0.28)	0.17
	24 hours vs 96 hours			1.39 (0.37, 2.40)	0.009
Week 3		37	0.073		
	0 hours vs 4 hours			0.0 (0.0, 0.0)	1.0
	0 hours vs 8 hours			-0.04 (-0.13, 0.05)	0.37
	0 hours vs 24 hours			-0.34 (-1.51, 0.83)	0.56
	0 hours vs 96 hours			-1.41 (-2.75, -0.07)	0.04
	4 hours vs 8 hours			-0.04 (-0.12, 0.05)	0.37
	24 hours vs 96 hours			-1.07 (-2.07, -0.06)	0.04

	Time zone	Participant Numbers	P value (Time)	Mean difference and 95%CI	P value for planned contrast
Week 4		38	0.004		
	0 hours vs 4 hours			0.0 (0.0, 0.0)	1.0
	0 hours vs 8 hours			-0.05 (-0.18, 0.07)	0.40
	0 hours vs 24 hours			-0.21 (-0.42, 0.01)	0.05
	0 hours vs 96 hours			-1.45 (-2.40, -0.50)	0.004
	4 hours vs 8 hours			-0.05 (-0.17, 0.07)	0.40
	24 hours vs 96 hours			-1.24 (-2.14, -0.34)	0.01
Week 5		34	<0.0001		
	0 hours vs 4 hours			-0.03 (-0.09, 0.03)	0.33
	0 hours vs 8 hours			0.06 (-0.07, 0.19)	0.35
	0 hours vs 24 hours			-0.21 (-0.90, 0.49)	0.55
	0 hours vs 96 hours			-2.34 (-3.54, -1.14)	<0.0001
	4 hours vs 8 hours			0.06 (-0.06, 0.18)	0.30
	24 hours vs 96 hours			-2.13 (-3.64, -0.62)	0.007

Table 4.5 shows the mean within-player differences from Match-day scores. The mean within-player differences in scores were small and not statistically significant between time points 0 hours, +90 minutes and +3 hours in that they ranged from zero to 0.21 points. However, between 0 hours and +36 hours there were large increases in the comfort score ranging from 2.6 to 3.5 points that were all statistically significant.

Table 4.5 *Match-day within-player differences*

Time zone	**Participant Numbers**	**P value (Time)**	**Mean difference and 95%CI**	**P value for planned contrast**
Week 1	19	0.001		
0 $^{\text{hours}}$ vs 90 $^{\text{minutes}}$			0.0 (0.0, 0.0)	1.0
0 $^{\text{hours}}$ vs 3 $^{\text{hours}}$			-0.11 (-0.27, 0.05)	0.16
0 $^{\text{hours}}$ vs 36 $^{\text{hours}}$			-3.15 (-4.73, -1.58)	0.001
Week 2	19	<0.0001		
0 $^{\text{hours}}$ vs 90 $^{\text{minutes}}$			0.0 (0.0, 0.0)	1.0
0 $^{\text{hours}}$ vs 3 $^{\text{hours}}$			0.21 (-0.01, 0.43)	0.06
24 $^{\text{hours}}$ vs 96 $^{\text{hours}}$			1.39 (0.37, 2.40)	0.009
Week 3	20	<0.0001		
0 $^{\text{hours}}$ vs 90 $^{\text{minutes}}$			0.0 (0.0, 0.0)	1.0
0 $^{\text{hours}}$ vs 3 $^{\text{hours}}$			-0.10 (-0.53, 0.33)	0.63
0 $^{\text{hours}}$ vs 36 $^{\text{hours}}$			-3.50 (-4.96, -2.04)	<0.0001
Week 4	20	<0.0001		
0 $^{\text{hours}}$ vs 90 $^{\text{minutes}}$			0.05 (-0.06, 0.16)	0.33
0 $^{\text{hours}}$ vs 3 $^{\text{hours}}$			-0.01 (-0.27, 0.26)	0.96
0 $^{\text{hours}}$ vs 36 $^{\text{hours}}$			-3.19 (-4.43, -1.95)	<0.0001

4.5 DISCUSSION

The LLCI when used in a competitive football environment was both reliable and responsive to change during both a football training week and under Match-day conditions. The instrument of lower extremity comfort, demonstrates a novel approach to calculate six anatomical sites of the lower extremity (foot, ankle, calf-Achilles, shin, knee, football boot) comfort. The instrument was validated in Chapter 3 within similar level athletes from the specified football codes. This measure of lower extremity comfort was intended to provide a tool for clinicians and athletes which was easy to implement providing prospective data to:

I. Prospectively monitor lower extremity comfort at multiple anatomical regions,
II. Create a baseline for comfort norms for individual players for future assessment,
III. To use prospectively in the event of injury to monitor rehabilitation progress.

The results indicate that measures of lower extremity comfort using the LLCI are reliable under stable conditions and are also responsive to clinical changes over time and therefore have an important potential in the context of monitoring player welfare. In the absence of any quantifiable scale, subtle changes in lower extremity comfort currently go undetected. The LLCI results indicated that lower extremity comfort can be detected and catalogued in different ways. For example the test period 0^{hours} to $+24^{hours}$ following Match-day will provide information on physiological muscle changes such as delayed onset muscle soreness and the extent of an injury can be monitored to provide data on the effectiveness of intervention treatment strategies. The test period 0^{hours} to $+24^{\text{hours}}$ or 0^{hours} to $+36^{\text{hours}}$ will provide information on player recovery from training or Match-days and can assist with weekly preparation for training, injury management or other interventions. The test period 0^{hours} to $+96^{\text{hours}}$ (pre-game) will allow evaluation of how an individual player has progressed during the week, identify any new musculoskeletal conditions, and enable pre-game intervention strategies or even be used as a tool to assess selection for a match.

Test-retest of comfort scores under the Weekday conditions showed the repeatability of comfort scores when the testing environment was constant, and how comfort changed with the passage of time. Weekday comfort analysis can be classified into three conditions.

Condition 1 (measures 0^{hours}, $+4^{\text{hours}}$ and $+8^{\text{hours}}$) involved recording of comfort on the same day where there were no changes to the environment in terms of training, or medical intervention. Under this condition ICC’s were high for comfort measures at 0^{hours} and $+8^{\text{hours}}$ (Table 4.2). Given the lack of difference in comfort scores between 0^{hours} and $+4^{\text{hours}}$ (Table 4.3), it was considered more relevant to test the ICC at a greater time interval (0^{hours} and $+8^{\text{hours}}$), to determine whether players repeated their scores. The results indicated that players were capable of recording comfort accurately as there were no significant changes in the scores between 0^{hours} and $+8^{\text{hours}}$. Had a difference been significant it would have indicated the environment changed sufficiently to alter comfort. The information obtained from Condition 1*,* which represented $+36^{\text{hours}}$ following Match-day results, provides an insight into aspects of lower extremity comfort following physical exertion. The data showed that lower extremity distress remained and does not alter until a significant change to the training environment. This may enable individualised strategies to assist post match recovery strategies.

Condition 2 (day two measures) recorded comfort +24 ^{hours} following the first recording of comfort. The change to the environment included overnight sleep, some rehabilitation interventions, and perhaps a light training session. Condition 3, occurred toward the end of the week, generally the day before Match-day. Condition 3 is +72 ^{hours} after Condition 2 and +96 ^{hours} after Condition 1 (0 ^{hours}) and represents a usual week of training, rehabilitation, and medical intervention where substantial changes to comfort will occur.

Table 4.3 indicates within player differences for comfort measures for all three Weekday conditions. Condition 1 included test-retest measures at three time points (0 ^{hours}, +4 ^{hours}, +8 ^{hours}) where the testing environment was not subject to interventions. The small mean differences and narrow 95% CI indicate the comfort measures and there being no significant change in comfort scores (P>0.05). The clinical interpretation of the results where there was no change to the testing environment; individuals were able to repeat their comfort scores on three separate measurement occasions within a test session over a five week period, indicating the comfort measures were repeatable.

Condition 2 (+24 ^{hours}) shows a lack of difference (P>0.0 5) for Weeks 3 and 5, but significant differences (P<0.0 5) for Weeks 1, 2, and 4. The statistical significance P<0.05 for 0 ^{hours} to +24 ^{hours} was expected because a change in environment occurred. These changes involve passage of time, sleep, rest and other physiological changes will alter neural stimuli which control comfort. Where comfort changes were not significant in Weeks 3 and 5, it is thought that changes in the environment were not influential in altering comfort scores. Condition 3, (+96 $^{\text{hours}}$) results were consistent with Condition 2 as a result of changes to the environment which involved a full week of football training or rehabilitation if not training. Test-retest of [Condition 2 $^{\text{versus}}$ Condition 3] and [Condition 1 $^{\text{versus}}$ Condition 3] indicate significance (P<0.0 5) for 80% of the data. This was an expected outcome indicating changes to comfort over time and participants altering their comfort measures in response to the passage of time and intervention strategies.

Conditions 1, 2 and 3, are shown in Figure 4.2 indicating five weeks of comfort results. For the period 0 $^{\text{hours}}$ to +4 $^{\text{hours}}$ and +4 $^{\text{hours}}$ to +8 $^{\text{hours}}$ there was no change in comfort scores confirming a stable testing environment, where comfort changes were not significant and for three testing periods, players consistently reported the same comfort. When the environment changed at +24 $^{\text{hours}}$ and +72 $^{\text{hours}}$, the individuals were able to indicate changes to comfort and altered comfort scores accordingly. This illustrated the sensitivity of the LLCI as a tool to record comfort.

The repeatability of recording comfort was assessed in a different test environment; Match-day conditions. For practical reasons, only three measures were taken over a short period of time as players regularly have post match commitments to attend. The results showed high ICC's for measures between baseline (0 $^{\text{hours}}$) and duration (+3 $^{\text{hours}}$) (Table 4.2). During this period players relax, hydrate and take food but there is no significant change to the environment in terms of comfort interventions. This is indicated by the lack of change in comfort scores when measures were taken +90$^{\text{minutes}}$ later (Table 4.3). Therefore it was considered a measurement between the first and final comfort measure suitable to calculate ICC's to test whether the recording of comfort was repeatable by the players.

The lack of significance for test-retest at two time points (Table 4.5) for within player differences for Match-day results highlight comfort did not change over a short period of time. For all test weeks P>0.05 for (0^{hours} v $+1.5^{\text{hours}}$) and (0^{hours} v $+3^{\text{hours}}$); mean differences were small and the 95% CI were narrow. However, with a change in the environment, the passage of time, significant differences occurred (P<0.01 for measures at $+36^{\text{hours}}$) for all weeks except Week 5 when only nine players participated. These results are represented by Figure 4.3. For the period 0^{hours} to $+3^{\text{hours}}$ there was no change in group mean comfort. The next test period $+36^{\text{hours}}$ following Match-day testing, comfort scores where significantly higher indicating as a group, the participants were capable of differentiating comfort as the environment changed.

The results confirm the hypothesis that the LLCI is a reliable method of measuring lower extremity comfort under two different sporting environments of Weekday training and Match-day playing. For two separate test conditions, Weekday and Match-day, when the testing environment was stable and measured over multiple weeks, the results show the measurement errors for all weeks were small and the ICC's >0.9 provide a high level of confidence in the reliability of the method when used under identical test conditions (Table 4.2). The test-retest results indicate good repeatability for all time points examined and provide confidence that the LLCI for measuring lower extremity comfort is reliable in players with a wide range of experience and when used under different conditions. Future analysis of the LLCI will involve testing the validity of the index to monitor injury (Chapter 5).

The reliability of the LLCI provides both individual and organisation confidence the data collected are not random but consistent with the status of lower extremity comfort. Collecting LLCI data will benefit individual players by setting benchmark comfort scores against which to compare future discomfort. Re-coding benchmark comfort will also assist medical staff by quantifying the degree of comfort, an area of medicine which to date has not evolved in this sport.

Current best practice for treating musculoskeletal injury within sporting organisations is for the medical staff to assess players for injury which is known. Alternatively, there is a responsibility for individual players to report any ailments. In large sporting organizations, such a policy, while well intended, does not result in full medical coverage. For example senior players often command more attention than younger players. Thus a measurement tool that is simple to administer and which covers lower extremity well being for an entire squad allows all players to be monitored effectively and below comfort thresholds can be identified by medical and conditioning staff for pre-emptive interventions.

The nature of injury necessitates focusing upon the site of musculoskeletal distress. However, compensation at adjacent regions also occurs, and often treatment intervention of the primary area does not address subtle changes and compensatory function which occur at other musculoskeletal linkages. Use of the LLCI model enables monitoring of not only the primary area of concern but also any changes to adjacent musculoskeletal areas and thus enables monitoring of the entire lower extremity as individual segments and as a whole unit.

The LLCI adopted for this body of work involved the measurement of six areas. Clinicians and researchers need to be mindful of the amount of data collected in a professional football environment. There are many time restraints placed upon a footballer, so this body of work attempted to ensure the lower extremity data collected was deemed worthwhile to both footballer and evaluator. Chapter 2 and 3 established the importance of lower extremity injury and those areas frequently injured. Hence, six evaluation markers was a balance between; (a) measuring enough anatomical segments to ensure good coverage of the lower limb and hence gathering meaningful data and (b) the LLCI not being onerous for football players to complete or medical staff to interpret.

4.6 CONCLUSIONS

Lower extremity injury management is an important component of sports medicine in both team and individual settings. The importance of comfort as a viable method to aid health and wellbeing is recognised as a viable method of assessing pain and discomfort. However, very few pre-emptive methods exist to detect discomfort. The use of measuring multiple anatomical areas to derive an overall lower extremity comfort score provides a new method of measuring lower extremity wellbeing.

This study shows the use of a lower limb comfort index as a reliable instrument to record lower extremity comfort in a football environment. It is anticipated the index is not limited to professional football but have application to other sports as well as clinical practice for general physicians, physiotherapists, podiatrists and those engaged in the management of lower extremity musculoskeletal injury.

CHAPTER FIVE

MONITORING OF LOWER EXTREMITY COMFORT AND INJURY IN ELITE FOOTBALL

This chapter is supported by the publication:

Kinchington, M., Ball, K., Naughton, G. (2010). Monitoring of lower extremity comfort and injury in elite football. The Journal of Sports Science and Medicine, Volume 9, Issue 4, 652-663.

5.1 ABSTRACT

Background: The LLCI was developed to provide a tool for clinicians and athletes to monitor lower extremity comfort at multiple anatomical regions. Chapter 4 established the reliability of the LLCI in a competitive football environment.

Objectives: Examine the relation between lower extremity comfort and injury in a cohort of professional footballers. The hypothesis for the study was that poor lower extremity comfort is related to *time loss events*.

Methods: Lower extremity comfort was recorded for 182 footballers during competition periods for the respective football leagues (Australian Rules, Rugby league, Rugby Union). Comfort zones were established for each individual; poor (red zone) comfort (median comfort $^{-2\ \text{comfort points}}$); usual (black zone) comfort (median $^{\pm 1\ \text{comfort points}}$) and high (blue) zone comfort (median $^{+2\ \text{comfort points}}$).

Specifically, the study tested the extent to which comfort zones were related to injury (*time loss events)*. To validate the use of comfort score, repeated measures analysis of variance was used to determine significant differences in injury rates between the zones, with post-hoc tests used to compute specific between zone differences. For all analyses, $P<0.05$ were considered statistically significant.

Results: A total of 3524 player weeks of data was collected from professional footballers encompassing three codes of football. The results of regression indicated that poor lower extremity comfort was highly correlated to injury ($R^2=0.77$) and accounted for 43.5 *time loss events* $/1000^{hours}$ football exposure. While poor comfort was predictive of injury 47% of all *time loss events* it was not statistically relevant ($R^2=0.18$).

Conclusions: Lower extremity comfort can be used to assess the well-being of the musculoskeletal status of a footballer. Poor comfort is associated with injury. The LLCI has good face validity and high criterion-related validity for the relationship between comfort and injury. The registering of lower extremity comfort contributes to the injury management paradigm by offering a method to monitor lower extremity health prospectively and assist with decision making when injury occurs.

5.2 INTRODUCTION

The football codes require superior levels of physical fitness and skill for competition. Participation at all levels of football (professional, amateur, pre-adult) is associated with a certain risk of injury. To benchmark the level of injury risk it has been estimated the risk of playing football (soccer), compared with the work environment, is 1000 times greater than high risk industrial occupations (Drawer & Fuller, 2002). Statistics from elite football leagues indicate injury epidemiology rates as high as 60-90% for football (soccer), 60-75% for Australian rules, 75-90% for rugby league and 55-80% for rugby union (Engström, Johansson, & Tornkvist, 1991; Gabbett, 2006b; Hagglund, Waldén, & Ekstrand, 2009; Lüthje, et al., 1996; Orchard & Seward, 2008). A study of injury in Australian football suggested the high rates of injury may affect the long-term viability of playing football as potential players seek other forms of activity (Norton, et al., 2001).

Injury risk modelling can be divided into extrinsic (environmental, ground surfaces, and training methods) and intrinsic (foot kinematics and lower extremity morphology) variables (Bahr & Holme, 2003; Van Mechelen, et al., 1992). The lower extremity has been identified as the primary region of the body vulnerable to injury (Chapter 3, Table 3.1), not only affecting the football codes, but also the majority of running based sports (Burns, Keenan, & Redmond, 2003; Gosling, Gabbe, & Forbes, 2008; Walden, et al., 2005; Wong & Hong, 2005). However, statistics on lower extremity injury vary greatly depending upon definition and methods of recording data. Lower limb epidemiology research is complicated by inherent difficulties of research design. Difficulties arise due to the vast array of confounders and interactions of internal and external factors that can influence epidemiology and biomechanical research (Bahr & Krosshaug, 2005). Divergent research conclusions for causes of injury are therefore likely, and difficult to measure. Links with injuries specific to the lower extremity and the football codes, include climate conditions (Orchard, 2002), ground surfaces (Gabbett, 2006b; Takemura, Schneiders, Bell, & Milburn, 2007), footwear (Wong & Hong, 2005), kicking action (Apriantono, Nunome, Ikegami, & Sano, 2006; Baczkowski, Marks, Silberstein, & Schneider Kolsky, 2006) and lower extremity morphology (Gabbe, et al., 2004; McManus, et al., 2004). While these and like individual risk factors have been identified and are often appropriately managed, the separate entities provide an incomplete description of the mechanisms ("chain of events"), which culminates in injury (Bahr & Holme, 2003; Murphy, et al., 2003).

A novel concept measuring lower extremity comfort over time, using a comfort index was established in Chapters 3 and 4 of this thesis. The instrument which is termed the Lower Limb Comfort Index, LLCI (Kinchington, Ball, & Naughton, 2010) provides quantitative data on the physical preparedness of an individual pertaining to the lower extremity. The sum of six segmental measures (foot, ankle, calf-Achilles, shin, knee and football boot) provide a mechanism for establishing base-line comfort for each individual.

Previous chapters in this thesis indicate the LLCI provides a tool to:

I. Prospectively monitor lower extremity comfort at multiple anatomical regions;
II. Create a baseline for comfort norms for individual players for future assessment;
III. To use prospectively in the event of injury to monitor rehabilitation progress.

The theory behind the LLCI was developed in Chapter 3 and contends that pain (discomfort) is a neural stimulus due to the interaction of nociceptive stimulation and the cerebral cortex. A discomfort (pain) stimulus via the neural networks of the body provides information about the state of comfort. Over a lifetime of experience, a databank of perceptions of pain (discomfort) is gathered from interrelated human experiences. Thus, pain stimulus can be considered innately individual, meaning different things to different people (Kolcaba & Steiner, 2000). The clinical application of comfort theory as a component of injury management is the use of a self-rating psychophysical comfort index (Figure 5.1). The setting of individual comfort benchmarks in sport for players can be used to monitor musculoskeletal health, plan for training and formulate prehabilitation and rehabilitation programs. If discomfort can be identified early, it may be possible to intervene before injury occurs. The data provide an assessment tool to inform individual players about the status of their own individual comfort for any nominated anatomical segment of the lower extremity. Data can also be useful to the medical teams who care for them. The outcome data if catalogued over a period of time would then establish baseline comfort markers, which would in turn act as a barometer for future assessment of comfort or discomfort. Similar systems are well documented including pain scales which are generally visual analogue scales or numerical rating scales (Williamson & Hoggart, 2005). Such scales are typically used reactively, following an injury event to gauge the severity of injury. For injury prevention, reactive measures are not beneficial. The frequent collection of comfort data in a state of relative comfort (prospective) enables cumulative episodes of comfort events to be established.

In the environs of elite sport, a player is rarely free from musculoskeletal discomfort and often will contend with multiple areas of discomfort at one time. The LLCI provides the player and medical-conditioning staff with quantifiable information about the state of multiple anatomical areas and the lower extremity as a whole. The index is therefore capable of capturing information about an injured area, and also adjacent body linkages which are subjected to compensatory movement. Captured data for any given week are compared to baseline comfort and therefore an assessment can be made about the overall state of lower extremity well-being.

The aim of this study was to examine the relation between lower extremity comfort scores and injury and also to measure the responsiveness of the LLCI to changes of comfort over time. Specifically, the study tested the extent to which comfort zones as measured by the LLCI were related to injury measured as *time loss events*. The use of time loss is widely used in football as a measure of injury (Orchard & Seward, 2008).

5.3 METHODS

The population base for this study comprised athletes from three dominant football codes played in Australia (rugby league, rugby union, and Australian rules). In agreement with the guidelines of the Human Ethics Committee of Victoria University, players provided informed consent prior and letters of support for the study were obtained from the respective organizations.

5.3.1 Data collection

Of 200 recruited football players, the final sample comprised 182 players. During the study 18 players (9%) dropped out (five due to long term injury, two through transfer to other teams, and 11 were omitted because of incomplete data records. Data for 182 players were analysed. In total, 5033 player weeks of data were collected with a mean of 28 (SD 5) weeks per player. The study was conducted during football competition periods for the respective football leagues and included a period of pre-season training.

5.3.1.1 Lower extremity comfort

Lower extremity comfort was collected prospectively for the period of the study, using the LLCI. The LLCI was developed to provide a tool for clinicians and athletes to monitor lower extremity comfort at multiple anatomical regions (Chapters 3 and 4). A sum score for lower extremity comfort was calculated for each player. The score represented an aggregation of six anatomical areas (foot, ankle, calf-Achilles, shin, knee, football boot), totalling 36$^{\text{comfort points}}$. Each anatomical area was scored between 0$^{\text{comfort points}}$ and 6$^{\text{comfort points}}$. A score of 0$^{\text{comfort points}}$ indicated extreme discomfort, being unable to run or jump, and 6$^{\text{comfort points}}$ was extremely comfortable (Table 5.1).

Table 5.1 *Lower Limb Comfort Index shows a numeric rating scale with fixed anchor points at key positions on the scale. Visual descriptive explanations provide further interpretation of the anchors relevant to physical requirements participating in football.*

<table>
<tr><td>Name:</td><td colspan="6">Place a score 0 to 6 in each box</td><td></td></tr>
<tr><td rowspan="2">Lower extremity Comfort: Rank each body area from 0-6 using the comfort descriptors</td><td>Foot</td><td>Ankle</td><td>Calf-Achilles</td><td>Shin</td><td>Knee</td><td>Footwear</td><td>Sum Comfort</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td>/36 maximum score</td></tr>
<tr><td colspan="7">COMFORT DESCRIPTORS

0 = extremely uncomfortable (unable to run or jump)
1
2
3= neither uncomfortable or comfortable (neutral)
4
5
6= zero discomfort (extremely comfortable; best ever feel)</td><td></td></tr>
</table>

Comfort zones were individualized for each player and were determined post hoc using median scores from the collected data. “Post hoc” for this study was defined as end of season (20-30 collected events). This was a deliberate design of the study to allow for tracking of significant changes to comfort levels. It is possible zone comfort may need to be re-set for a variety of reasons including surgery, football conditioning, changing musculoskeletal maturity or other relevant football factors.

Three comfort zones were established for each individual footballer. Each zone was apportioned an arbitrary colour to reflect level of comfort. Red zone represented poor comfort (median comfort $^{-2\ \text{comfort points}}$). Black zone was associated with median or usual comfort (median $^{\pm 1\ \text{comfort points}}$) and blue zone was a measure of high comfort (median $^{+2\ \text{comfort points}}$), Table 5.2. The apportioning of the upper and lower zones was established by trials using other scores above and below the median. The use median $^{\pm 1\ \text{comfort points}}$ were too narrow to delineate poor and high comfort zones because this did not allow for some fluctuation in comfort. Scores of median $^{\pm 3\ \text{comfort points}}$ created a range too wide to establish meaningful outcomes. Perceptions of comfort and performance are empirical measures and by their nature, will vary. Therefore, a median range was deemed appropriate.

Table 5.2 *Lower Limb Comfort index (LLCI) zones*

Comfort Zone	**Formula**
Red (poor comfort)	median comfort $^{-2\ \text{comfort points}}$
Black (usual comfort)	median comfort $^{\pm 1\text{comfort point}}$
Blue (high comfort)	median comfort $^{+2\ \text{comfort points}}$

5.3.1.2 Collection of comfort data

All data were collected in a standardised manner under the supervision of the researcher or a club official, who was familiar with data collection protocol. Weekday comfort data collection occurred at the premises of participating football clubs in an environment that was consistent and familiar to players. Comfort data were recorded on one occasion, at the same time each week, which represented 24-36 hours post Match-days.

5.3.2 Injury data collection and definitions

Information of injury was collected by obtaining statistics gathered by fitness and medical staff of respective organisations. Injury data were collected routinely for the teams and did not represent an increase in workload for the support staff. Injury was defined as a *time loss event*. It included any event which resulted in absence from training or match participation. Training was defined as completion of a full regular training session. Match-day was defined as a competitive scheduled match organized by the respective football leagues. For the purposes of this study, a *time loss event* was tabled only once for any given week. Where two or more field based training sessions were missed, in any given football week, only one (1) *time loss event* was recorded for the week. In the study here-in, an activity such as a field-based rehabilitation or “off-legs” session would be considered a *time loss event.* The reasoning was where a participant does not fully participate in a scheduled training session, the capacity for achieving the same level of football skill and / or physical conditioning will be less and thus potentially compromise performance. This injury definition has previously been used in football studies (Dvorak & Junge, 2000). Furthermore, the area of performance and injury is examined in an extension study (Chapter 8). Only injuries applicable to the lower extremity (knee, shin, calf-Achilles, ankle, foot and any combination thereof) were recorded. Any injuries outside the areas described were not classified as *time loss events.*

Injury incidence was used to define the onset of a new injury (Orchard & Seward, 2008). This study was not concerned with injury reoccurrence, but rather the merits of the association between comfort and injury *(time loss event)*. Once a full training session was completed or match participation resumed, the player was considered free from injury. Therefore, injury reoccurrence definitions were not applied. Where injury reoccurred following a return to one regular training session or match, any subsequent *time loss event* were treated as a new injury.

Time loss events were classified three ways:

I. Injuries /1000 $^{\text{hours}}$ football exposure;
II. Predicted *time loss events* (Predicted $^{\text{TLE}}$);
III. Known *time loss events* (Known $^{\text{TLE}}$).

Injuries to the lower extremity / 1000$^{\text{hours}}$ are commonly used to compare injuries relative to exposure and enable comparisons to be made to other football related studies and other sports (Dvorak & Junge, 2000; Hagglund, Waldén, & Ekstrand, 2003). This study compared lower extremity comfort zones (poor, usual and high) to injury / 1000 $^{\text{hours}}$ football exposure. This enabled quantitative comparisons between levels of comfort and injury.

Classifying *time loss events* into Predicted $^{\text{TLE}}$ and Known$^{\text{TLE}}$ enabled a determination of whether poor comfort was predictive of injury. A Predicted $^{\text{TLE}}$ was an injury occurring during the football week (training sessions or match) following the recording of poor (red zone) comfort (Predicted $^{\text{TLE}}$ = LLCI $^{\text{data pre injury}}$). Such injuries are generally non-contact or overuse in nature. An example of a Predicted $^{\text{TLE}}$ is poor (red zone) calf muscle comfort or midfoot pain which is registered using Table 5.1, pre-training or match, and the player subsequently proceeds to a *time loss event* during the ensuing football week. A Known ^{TLE} was as an injury occurring before the recording of lower extremity comfort (Known ^{TLE} = LLCI $^{\text{data post injury}}$).These injuries are generally contact in nature or a planned decision to rest a footballer from training or a match due to musculoskeletal discomfort. When a Known^{TLE} is determined, the lower extremity comfort score provides confirmation of discomfort and the limitations on physical activity (Table 5.1 comfort descriptors).

5.3.3 Statistical methods

Data were analysed using SPSS v15.0 for Windows (2004). For all analyses, P<0.05 were considered statistically significant. Continuously distributed variables were summarized as means, standard deviations (SD) and 95% confidence intervals (95% CI) where appropriate. To describe the sample, summary statistics of the mean and median comfort score were computed together with the mean and median percentages of how many days players fell in poor (red), usual (black), or high (blue) comfort zones. Additional mean and median scores of *time loss events* and events in each zone injured, no injury events, injury prevalence, predicted injuries and injury mechanism were also computed. To display results graphically, box plots were used to compare outcomes between groups. In the plots, the dark line represents the median value, the box represents the 25% to 75% percentiles, and the whiskers show the range. Data points more than 1.5 times above or below the inter-quartile range are marked as outliers. Scatter plots were used to display relationships between two continuous variables. The degree of the association between continuous variables was described using Pearson's correlation coefficient (r) or the R square value from a linear regression model.

Categorical data such as rates of injury were summarized using percentages. To validate the use of comfort score, repeated measures analysis of variance was used to determine significant differences in injury rates between the zones, with post-hoc tests used to compute specific between zone differences. Analysis of variance is robust to some departures from normality but because the data were not entirely normally distributed, a Friedman's non-parametric repeated measures test was used to verify that the P values were not biased towards statistical significance.

5.4 RESULTS

Anthropometric data for participants were: age: mean 24.3 years (SD 3.6), mass 94.7kgs (SD 11.0); height 185.4 cm (SD 6.3). No significant differences in anthropometric measurements between the three different codes of football existed. The players from three codes of professional football were well matched for age and height. There was a large difference in weight between players from Australian Rules and the rugby codes but had no effect on the results (Table 5.3). The differences in body types between the football codes, is due to the nature of the football codes. Australian Rules football is a high volume running game (Norton, et al., 2001) compared to the collision and heavy contact associated with the rugby codes (King, Hume, Milburn, & Guttenbeil, 2010).

Table 5.3 *Characteristics of participants*

	Age (years) Mean (SD)	Height (cms) Mean (SD)	Mass (kgs) Mean (SD)
Australian Rules Football	24.7 (4.2)	186.7 (6.7)	86.5 (8.1)
Rugby League	23.8 (3.1)	184.3 (5.6)	97.9 (8.9)
Rugby Union	24.8 (3.3)	185.2 (6.8)	102.4 (10.7)

5.4.1 General lower extremity comfort of 182 professional footballers

Figure 5.1 *Lower extremity comfort for 182 professional footballers classified into poor (red zone) comfort, usual (black zone) comfort, and high (blue zone) lower extremity comfort categories.*

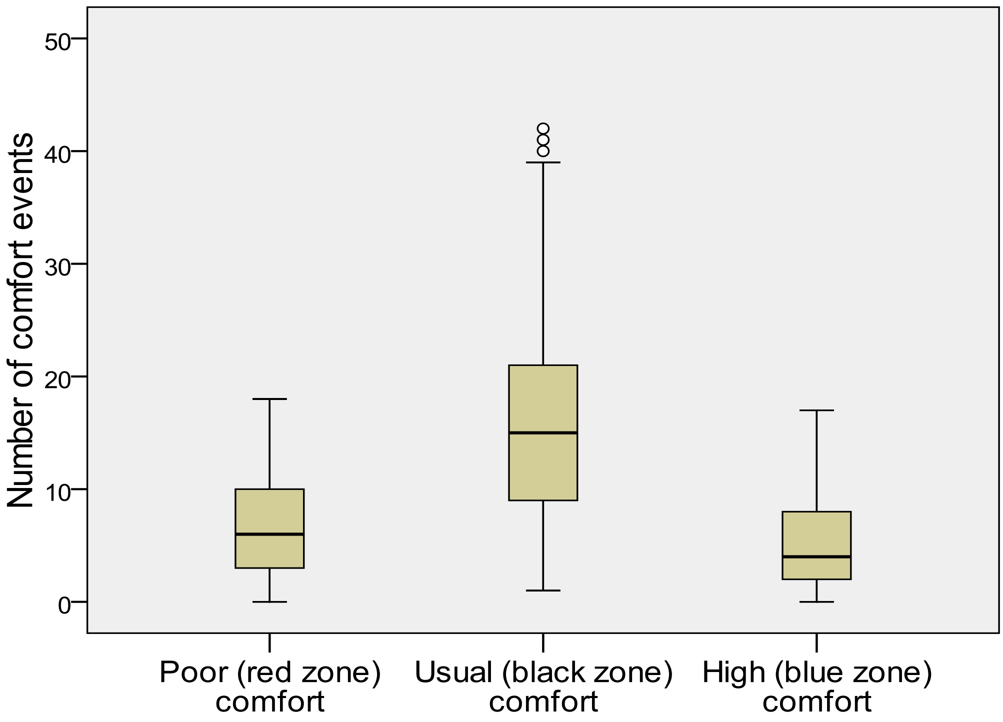


Figure 5.1 shows the box plots for the lower extremity comfort events for all players. Usual (black zone) comfort had a median value of 15 events (range 1 to 42) per player. Poor (red zone) comfort had a median of six events (range 1 to18) and high (blue zone) comfort had a median of four events (range 1 to 17) indicating variations around median comfort range (black zone comfort). Usual comfort, calculated by median $^{\pm 1 \text{ comfort points}}$ for each player, accounted for 58.6% of all comfort events (N=5033). Within the professional football environment examined, 23% of comfort scores recorded was categorized as poor (red zone) comfort, which corresponds closely with the number of *time loss events* (25.6%), recorded over the study period. Only 18% of players recorded high (blue zone) comfort responses, indicative of the demands placed upon the lower extremity musculoskeletal system associated with football participation.

5.4.2 Relation between comfort and injury for the football cohort

The relation between lower extremity comfort and injury was examined by:

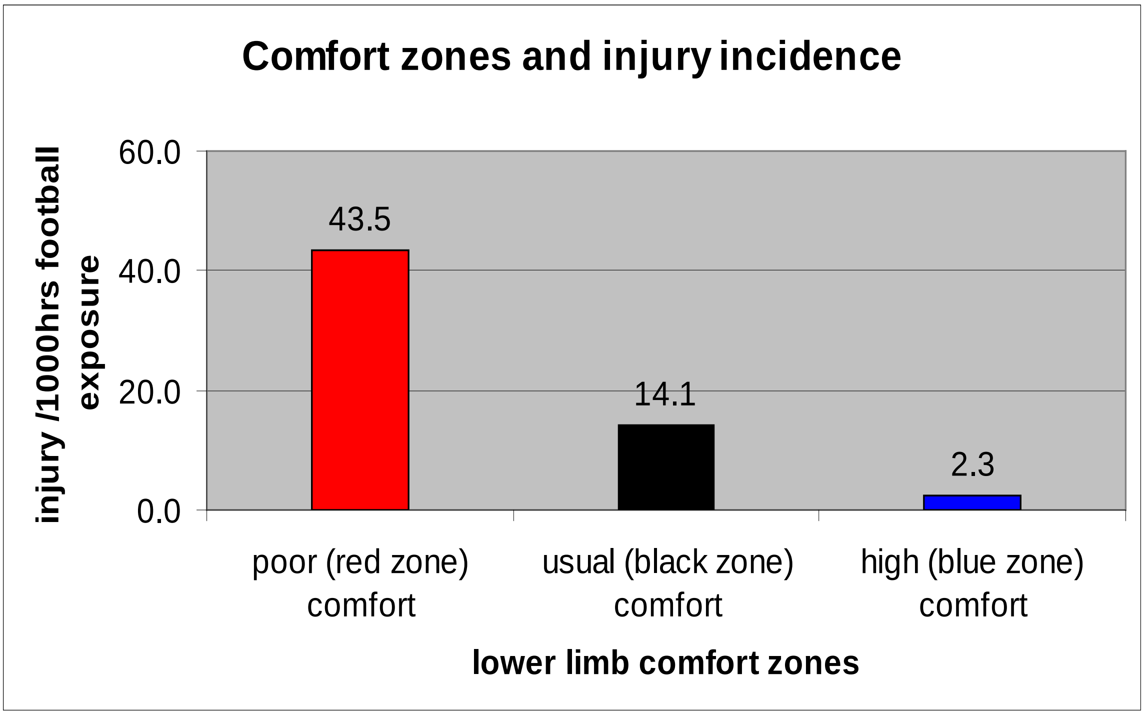
I. Calculating lower extremity injury incidence/1000$^{\text{hours}}$ football exposure
II. Analysing lower extremity comfort zones and *time loss events* (Predicted $^{\text{TLE}}$ and Known $^{\text{TLE}}$)
III. Determining the capacity of poor comfort to be predictive of injury

5.4.2.1 Lower extremity injury Incidence/1000 $^{\text{hours}}$ football exposure

Overall injury for the study was calculated as 65.8 *time loss events* /1000 $^{\text{hours}}$ football exposure. Figure 5.2 shows the associate between comfort zones and *time loss events* using injuries/1000 $^{\text{hours}}$ of football exposure. Data for all players was analysed separately and collapsed into the three comfort zones. The incidence of injury was 43.5 *time loss events* / 1000^{hours} of football exposure when lower extremity comfort was poor (red zone). The injury incidence rate was only 14.1/1000^{hours} for usual (black zone) comfort and 2.3/1000^{hours} when lower extremity comfort was high (blue zone). The results show poor lower extremity comfort was the major contribute to overall lower extremity injury. The low injury incidence when comfort was within the usual (black zone) comfort range or high (blue zone) comfort range, shows the possible protective role comfort may have against injury.

There were no significant differences in injuries/1000^{hours} between the different codes of football studies; although Australian Rules had less injuries/1000^{hours} (50.9) compared to the Rugby codes (Rugby Union, 68.9; Rugby League, 67.4). The reason for high injury exposure in the rugby codes were due to the collision-contact nature of injury sustained compared to more non-contact injuries for Australian Rules.

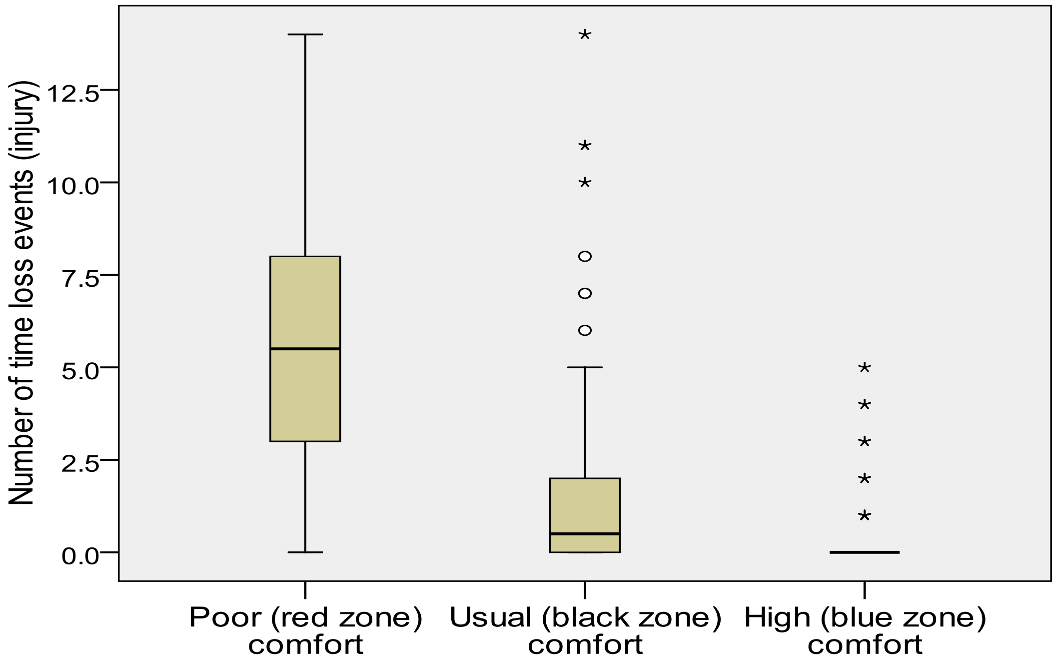
Figure 5.2 *Lower extremity comfort and injury/1000 hours of football exposure for 182 professional footballers.*



5.4.2.2 The influence of comfort zones on all injury (predicted TLE and known TLE)

Figure 5.3 shows poor (red zone) comfort was associated with the largest number of *time loss events.* When the group (N=182) recorded poor lower extremity comfort, the median time loss (injury) was 5.75 events.

Figure 5.3 *Time loss events (injury) classified by lower extremity comfort zones; poor (red zone), usual (black zone), and high (blue zone), for 182 professional footballers.*



For usual (black zone) comfort the median time loss was 1.0 event and for high (blue zone) comfort, the median time loss was zero events. The range of *time loss events* for poor comfort (red zone) was 0-14 events, with 50% of time loss between 3 and 8 *time loss events*. The majority of usual comfort (black zone) injury events were in the range 0-2 and zero when respondents registered high (blue zone) comfort. The data indicates when players recorded high comfort scores; there were no *time loss events* (injury) due to lower extremity discomfort except for five outliers. The injury data obtained from the classification of comfort into three zones is clinically relevant regardless of the injury type (Predicted ^{TLE} and Known ^{TLE}) because it quantifies discomfort, enabling clinicians to monitor the status of players, and implement programs to ensure an athletes lower extremity comfort is well maintained.

Figures 5.4, 5.5, and 5.6 and Table 5.4 further explore the relationship between comfort zones and *time loss events*. The scatter plots illustrates that *time loss events* were strongly associated with poor (red zone) comfort (R^2 = 0.77) and not significant with usual (black zone), R^2 = 0.48 or high (blue zone) comfort (R^2 = 0.15).

Table 5.4 confirms *time loss events* were significantly correlated to poor (red), usual (black) and high (blue) comfort scores. The strongest correlation was for poor (red) comfort scores, followed by usual (black) comfort scores. Although the P-value for high (blue zone) comfort was statistically significant for injury, the correlation coefficient remained low (0.39) which indicated that only 15% of the variation in all *time loss events* was explained by high (blue) comfort events. The high P-value is due to small values quickly become statistically significant with a large sample. The R^2 value is more relevant. In general in clinical work, 0.39 is considered a weak correlation (Zou, Tuncali, & Silverman, 2003).

Table 5.4 *Correlation between all time loss events and poor (red zone), usual (black zone) and high (blue zone) comfort events in 182 players.*

	Pearson correlation coefficient	**Linear regression R^2 value**	**P value**
Poor (red zone) comfort correlation to injury	0.88	0.77	<0.0001
Usual (black zone) comfort correlation to injury	0.69	0.48	<0.0001
High (blue zone) comfort correlation to injury	0.39	0.15	<0.0001

Figure 5.4 *Relationship between poor (red zone) comfort and time loss events (injury).*

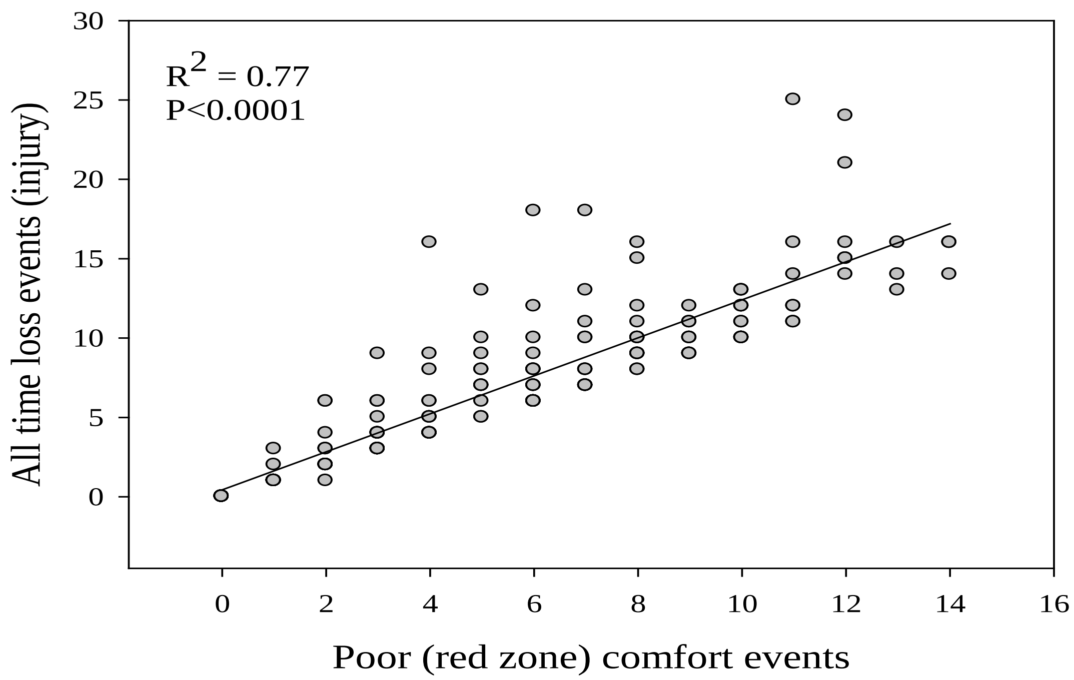


Figure 5.4 shows a small number of *time loss events* when poor (red zone) comfort events are low. For example, the number of *time loss events* was small

when poor (red zone) comfort events (0 and 2) were low. As the number of poor comfort events increased, there was a corresponding increase in *time loss events* (injury) with a strong linear relationship (R^2 = 0.77) between poor comfort and all *time loss events* recorded by the group.

Figure 5.5 *Relationship between median-usual (black zone) comfort and time loss events (injury).*

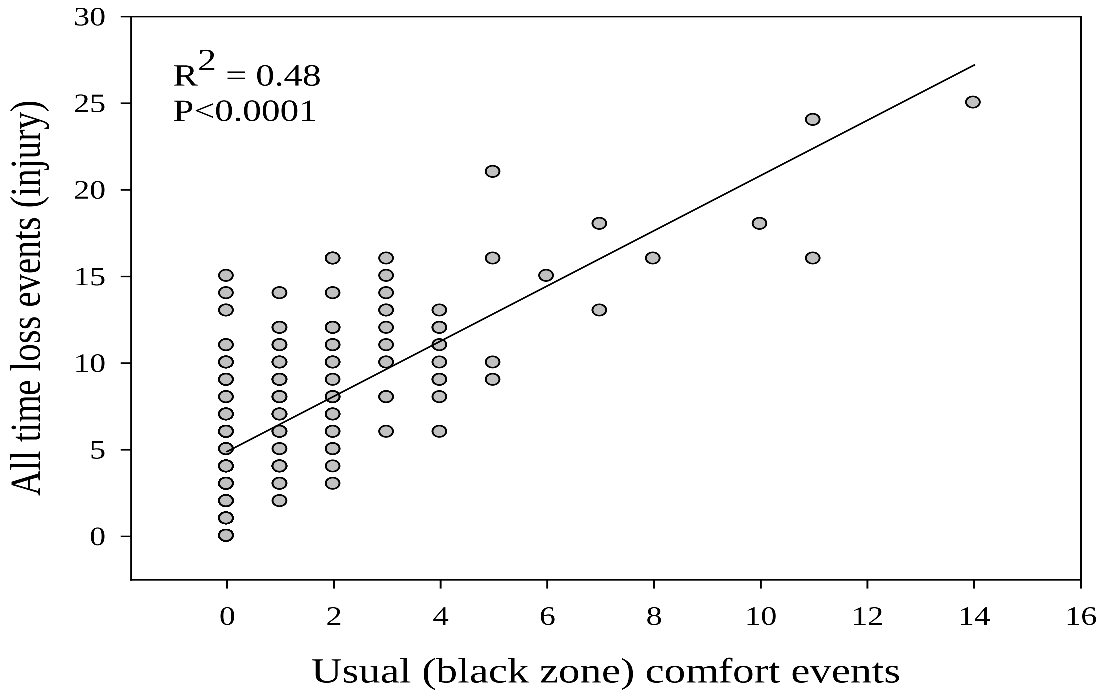
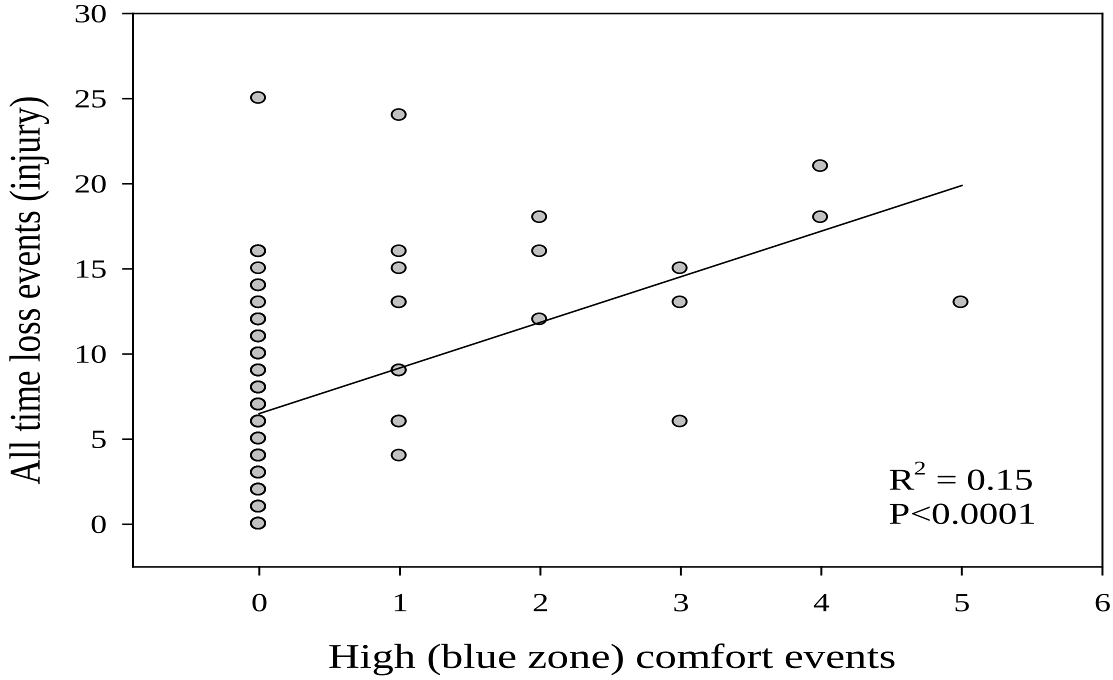


Figure 5.6 *Relationship between high comfort (blue zone) and time loss events (injury).*



As comfort improved as described in Figure 5.5 (regular comfort v *time loss events*) and Figure 5.6 (high comfort v *time loss events*) the number of *time loss events* (injury) was fewer. As a consequence, there was a weaker relationship for *time loss events* between black zone comfort and all injury events recorded by the group (R^2 = 0.48). Figure 5.5 shows 108 *time loss events* could not be accounted for by usual (black zone) comfort (zero) events. In usual (black) zone comfort, the majority of *time loss events* were 0-4 comfort events, whereas for poor (red) zone comfort, the majority of *time loss events* occurred between 4-8 comfort zone events. Similarly, a weak relationship was observed for high (blue) zone comfort and *time loss events* (R^2 = 0.15), with 161 *time loss events* not associated with high comfort. The clinical significance of these results is that poor comfort (red zone) is a measure of injury and subsequent *time loss events,* while high comfort (blue zone) is protective against injury.

5.4.2.3 Determining the capacity of poor comfort to be predictive of injury

Two aspects of assessing relation between poor comfort and *time loss events* were assessed:

I. Those occasions where poor (red zone) were not well correlated with injury was examined to test the inverse relationship of a poor comfort association with injury. In these situations, the individual footballers reported poor comfort scores, but were still capable of participating in full training sessions and matches. Figure 5.7 shows the sensitivity of comfort in the determination of injury; i.e. where poor (red zone) comfort zones had a weak correlation to *time loss events*.

Figure 5.7 *Poor (red zone) lower extremity comfort not associated with injury*

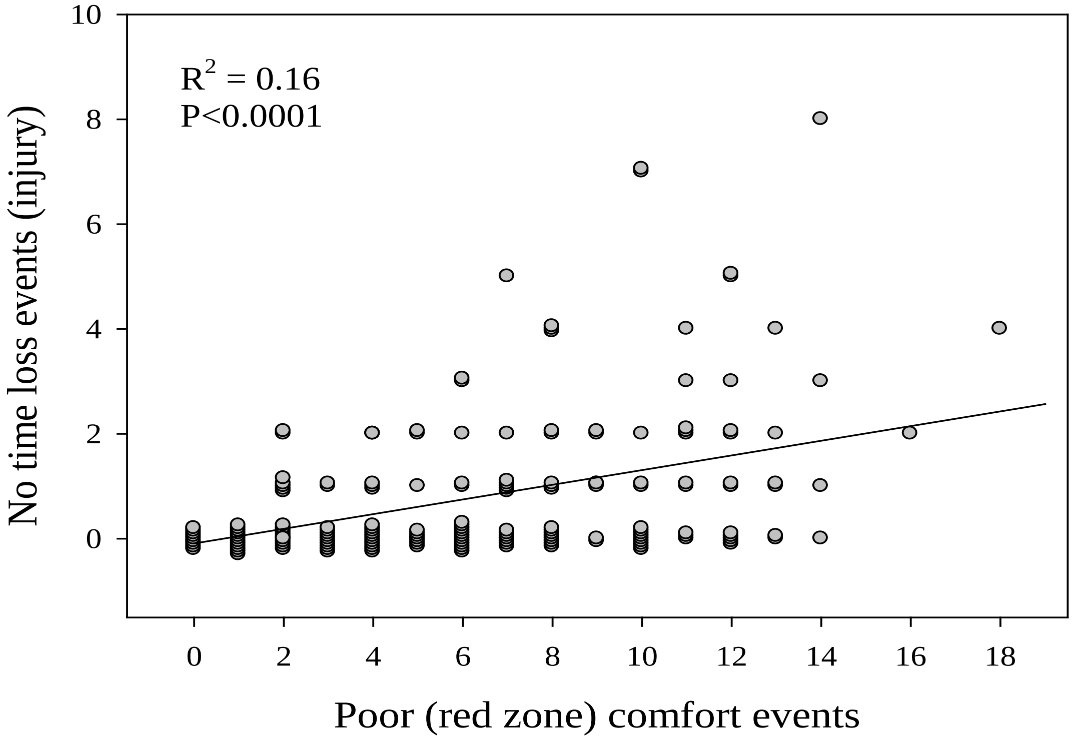
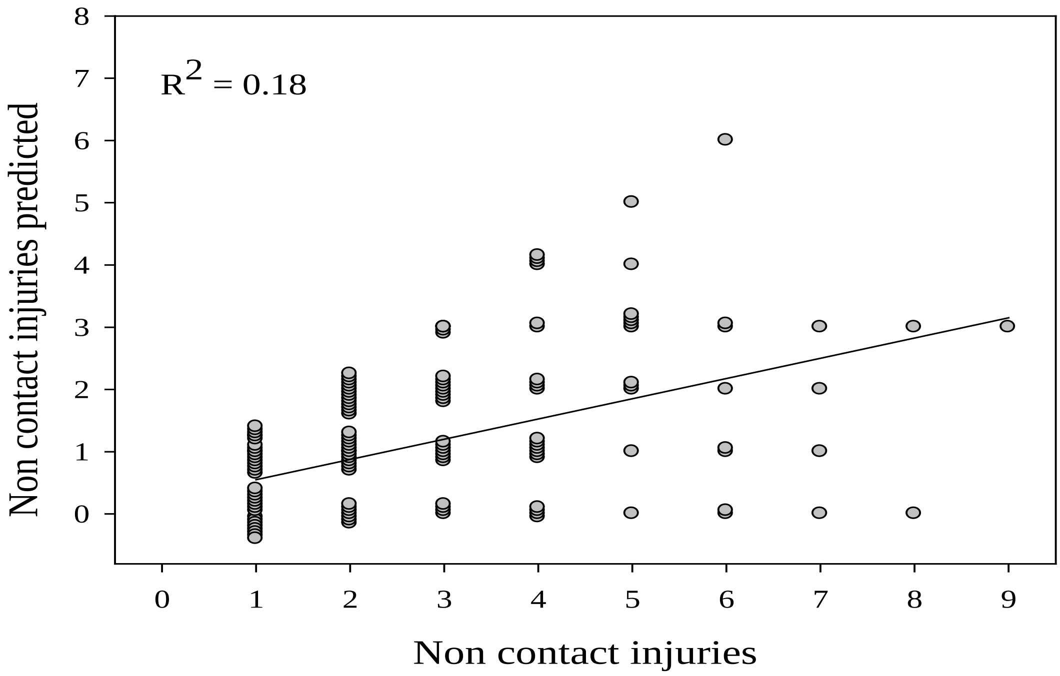


Figure 5.7 shows when two poor (red zone) comfort events were registered, poor comfort was not predictive of time loss on 1-2 occasions. At the other end of the graph, on the 18 occasions, poor (red zone) comfort was recorded, poor comfort was not predictive of injury on only four occasions. The maximum number of times poor comfort was associated with no *time loss events* was eight. The weak correlation (R^2 = 0.16) between poor (red zone) comfort and no *time loss events* provides confidence the method of measuring comfort by use of the LLCI is a valid test of determining *time loss events*. Where poor comfort did not result in missed training or match, this can be attributed to player discomfort not being clinically important enough to prevent full training or match participation.

II. Poor lower extremity comfort as a predictor of injury (Predicted ^{TLE})

To assess whether lower extremity comfort was predictive of injury, player comfort data was extracted from all injury data to examine individuals who sustained an injury in the week following comfort data collection. Correlations were made between the incidence of new non-contact *time loss events* and comfort events recorded immediately before injury incidence (Figure 5.8).

Figure 5.8 *Injury predicted by poor (red zone) lower extremity comfort*



While, a weak correlation between non-contact *time loss events* and prediction of *time loss events* (Predicted ^{TLE} = LLCI $^{\text{data pre injury}}$) was calculated ($R^2$ =0.18), poor (red zone) lower extremity comfort was predictive of injury on 47% of occasions. Of the 423 non-contact events recorded, 202 injuries were predicted by poor (red zone comfort). While the result does not have high statistical correlation, the result has high clinical relevance for those who deal with musculoskeletal injury. With caution, poor (red zone) comfort as a measured by using the LLCI can be used as a clinical tool to manage training and prehabilitation strategies to ensure poor comfort does not progress to *time loss events*.

5.4.3 Case studies of comfort and *time loss events*

To illustrate comfort variations over a given time period within the study, data was extracted for three players who were considered representative of the group. Player A, (Table 5.5); Player B, (Figure 5.9); and Player C, (Figure 5.10) show how overall lower extremity comfort fluctuated throughout the study and the effect on *time loss events*. The measure of individual anatomical segmental comfort data (Table 5.8 and Figure 5.9) provided information on how segmental comfort contributed to overall lower extremity comfort and highlights the importance of measuring multiple segments. The information provides data on how pain responses at one segment, due to injury, affects comfort at another segment. Figure 5.10 illustrates how training participation patterns and *time loss events* can be tracked over a timeline and provides a direct comparison between comfort and *time loss events*.

5.4.3.1 Case study player A

Table 5.5 *Lower extremity comfort scores over a 25 week period for one player. Highlighted cells indicate poor comfort scores.*

Week	Foot Comfort score	Ankle Comfort score	Calf-Achilles Comfort score	Shin Comfort score	Knee Comfort score	Footwear Comfort score	Sum Comfort (maximum score=36)
1	6	5	3	5	5	6	**30**
2	6	5	4	5	5	6	**31**
3	6	5	3	5	5	6	**30**
4	5	5	4	5	5	6	**30**
5	5	5	3	5	5	6	**29**
6	5	5	5	5	5	6	**31**
7	5	5	4	5	5	6	**30**
8	5	5	3	5	2	5	**25**
9	5	5	3	3	3	5	**24**
10	5	5	3	5	2	5	**25**
11	5	3	5	5	3	5	**26**
12	5	3	5	5	4	5	**27**
13	5	5	4	5	4	5	**28**
14	3	5	4	5	4	5	**26**
15	3	5	4	5	5	5	**27**
16	3	5	4	4	5	6	**27**
17	2	5	4	5	5	6	**27**
18	2	5	4	5	5	6	**27**
19	5	5	5	5	5	5	**30**
20	5	5	5	5	5	6	**31**
21	5	5	5	5	5	6	**31**
22	5	5	5	5	5	6	**31**
23	5	5	5	4	5	6	**30**
24	5	2	5	5	3	6	**26**
25	5	2	5	5	3	6	**26**
Median	5	5	4	5	5	6	**28**

Number of Poor Comfort Scores	Foot 5	Ankle 4	Calf-achilles 6	Shin 1	Knee 6	Footwear 0	Lower extremity 6
High (blue) comfort	Median Score + 2 comfort points >29						
Usual (black) comfort	Median Score ± 1 comfort points 27--29						
Poor (red) comfort	Median Score - 2 comfort points <27						

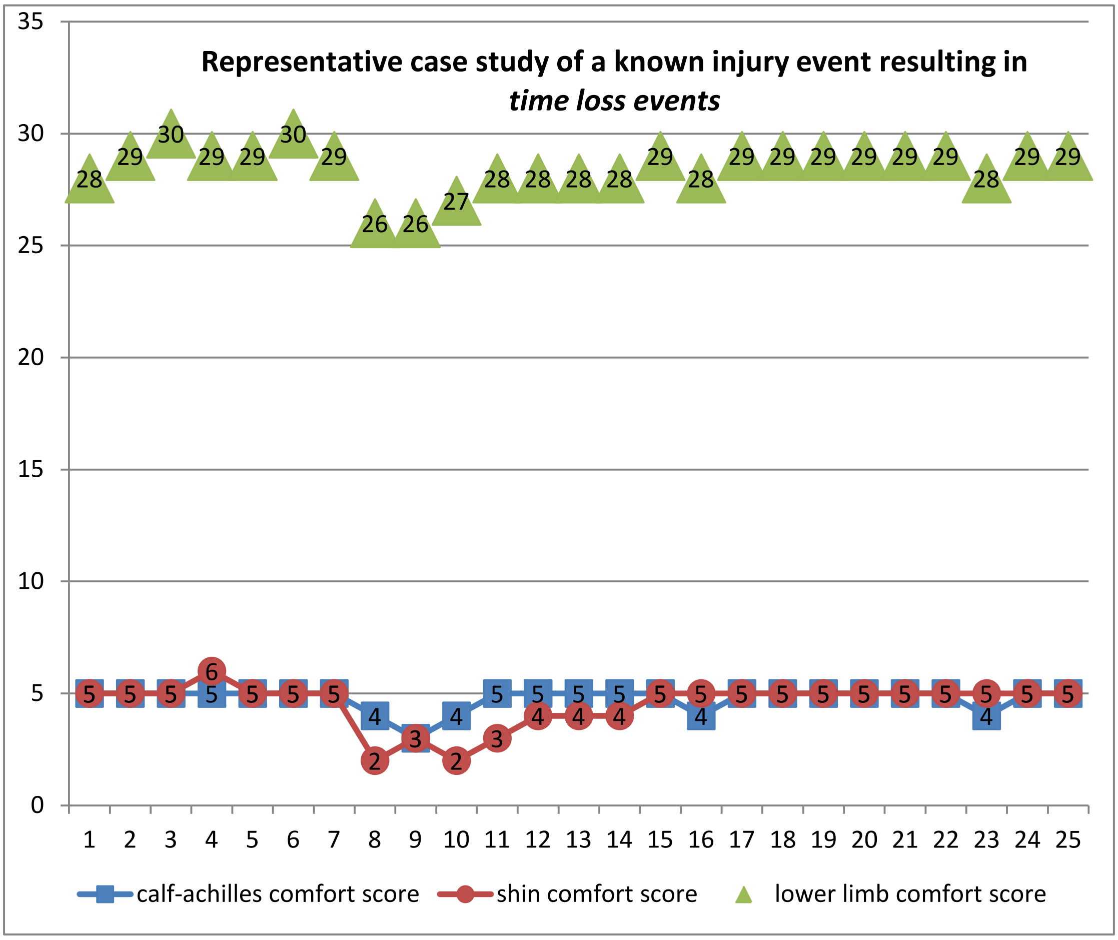
Table 5.5 shows data for Player A, who was selected at random from the cohort. Comfort scores for individual anatomical segments (foot, ankle, calf-Achilles, shin, knee, footwear) provided a sum comfort score for a given week. The data collection was repeated weekly for the representative case over a 25 week period. Medians for each anatomical segment (foot, ankle, calf-Achilles, shin, knee, footwear) and overall comfort of the lower extremity were calculated. Using the formula (Table 5.2), comfort zones were then established; poor (red zone) comfort were calculated as scores <27 comfort points. Usual (black zone) comfort range was inclusive of scores 28 ± 1 comfort point. High (blue zone) comfort was assigned to scores >29 comfort points. Individual anatomical segmental medians were also calculated.

Comfort data for Player A, indicated the calf-Achilles complex was the least comfortable region of the lower extremity, while all other sites had a median of 5 comfort points. During the collection period, scores fluctuated around the median for all of the individual anatomical segments. These scores were representative of group data comfort variations over the 25 week collection period. Lower extremity comfort was recorded as poor (red zone) on six occasions due to knee, calf and ankle discomfort. The highlighted cells within the table, for both individual anatomical segments and sum comfort, represent scores less than median for the anatomical segments which equate to poor comfort.

5.4.3.2 Case study player B

Figure 5.9 is representative of how overall lower extremity comfort at different anatomical regions of the body changed over a period of 25 weeks. Lower extremity discomfort registered by Player B, shows the effect of shin discomfort (week 8) and overall lower extremity comfort which reduced from 29 $^{\text{comfort points}}$ pre-incident to 26 $^{\text{comfort points}}$. The incident was a contact event sustained in a match and subsequently registered by the player as poor (red zone) comfort. The incident resulted in a *time loss event* during week 8. This example represents an occasion where the injury was classified as a Known $^{\text{TLE}}$ as the incident occurred prior to the recording of comfort (Known $^{\text{TLE}}$ = LLCI $^{\text{data post injury}}$).

Figure 5.9 *Representative case study of a known time loss event. The x-axis represents player comfort weeks, 1-25; the y-axis comfort scores 0-35.*



Overall lower extremity comfort reduced from a median score of 29 comfort points, to a poor (red zone) comfort (26 comfort points). Lower extremity comfort did not return to usual (black zone) comfort range until week 11. The Known TLE between weeks 8-11 were associated with poor (red zone) comfort for the lower extremity due to shin discomfort (less than median 5 comfort points). When lower extremity comfort returned to usual (black zone) range in week 11, a return to full training and Match-day participation occurred.

To illustrate the effect of musculoskeletal compensation due to comfort variations, *the time loss event* which was attributed to poor shin comfort also affected calf comfort (weeks 8-10). At the time of injury, shin comfort fell from 5 comfort points to 2 comfort points. Calf-Achilles comfort fell from 5 comfort points (week 7) to 3 comfort points (week 9) and did not return to usual comfort until week 11. The graph illustrates that as the footballer returned from injury, the overall lower extremity comfort remained within the player's usual (black zone) comfort range for weeks 11-25, not missing any further training or matches due to lower extremity injury. Shin comfort did not return to pre-injury comfort until week 15.

5.4.3.3 Case study player C

Figure 5.10 *Shows lower extremity comfort, participation in training sessions, time loss events, predicted and known injury events for one player whose data were representative of the sample. The x-axis represents player comfort weeks, 1-25; the y-axis comfort scores 0-35.*

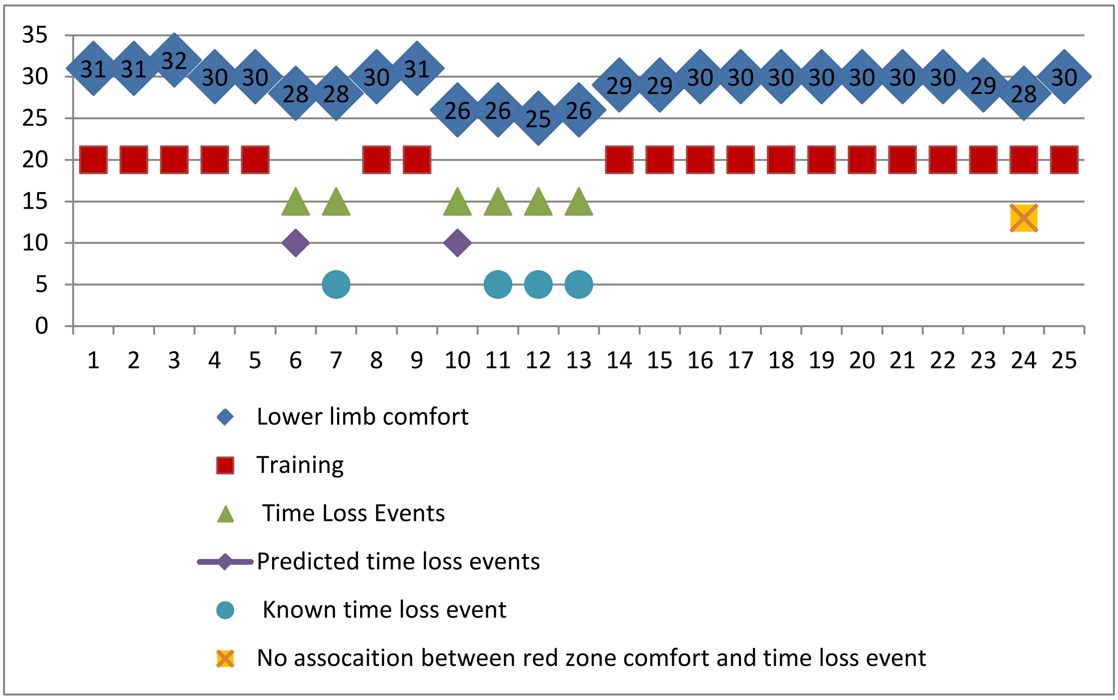


Figure 5.10 shows the pattern of training participation, *time loss events*, Predicted $^{\text{TLE}}$ and Known $^{\text{TLE}}$ for data of a player who was represenattive of the group. The median lower extremity comfort score for Player C, calculated over a period of 25 weeks was 30 $^{\text{comfort points}}$. A score of median $^{\text{-2 comfort points}}$, indicated poor comfort. A score of median $^{\text{+ 2 comfort points}}$ was labelled high comfort. Where comfort scores were within usual comfort range (29 $^{\text{comfort points}}$ to 31 $^{\text{comfort points}}$) or higher, full training participation occurred over the period. On only one ocassion a high score of 32 $^{\text{comfort points}}$ was recorded in week 3. This highlighted the demands of professional football on the lower extremity and supports the group data (Figure 5.1) where high lower extremity comfort is infrequent during in-season football. Poor comfort occurred in weeks 6, 7,10,11,12, 13 and 24. In all weeks of poor comfort, *time loss events* were recorded except for week 24, during which poor (red zone) comfort was not associated with a *time loss event*. Two new *time loss events* occurred in weeks 6 and 10, during which poor (red zone) comfort, was predictive of injury (Predicted $^{\text{TLE}}$ = LLCI $^{\text{data pre injury}}$). In weeks 7, 11-13 *time loss events* were classfified as Known $^{\text{TLE}}$ as these weeks followed new injury events in weeks 6 and 10.

5.5 DISCUSSION

The results from this study indicated a strong relationship between poor lower extremity comfort and injury when defined as a *time loss event*. The use of a comfort index (LLCI) was a novel method of prospectively monitoring lower extremity comfort in a cohort of elite footballers from three different football codes. The comfort index was sensitive in assessing comfort by cataloguing fluctuating comfort scores for 182 professional footballers and the creation of high and low comfort tiers around a median comfort score to examine the relationship between comfort and injury. The concept of lower extremity comfort has important relevance for future use in research and in clinical practice. High comfort scores can be interpreted as high comfort aligned to a protective mechanism for lower extremity injury.

This body of work is unaware of comfort as a concept previously being used prospectively in a comfort rating scale applied to the lower extremity for elite or amateur sport. However, psycho-physiological comfort ratings have been used in professions such as nursing (Chiu & Wang, 2007) and military (Mundermann, et al., 2003b) to assess footwear comfort. An advantage of the LLCI is the prospective recording of comfort. When an injury occurs, a discomfort event can be compared to a catalogue of comfort experiences (baseline comfort), providing a measure of the severity of the injury. Such information and recall is not possible with reactive pain scales if there is no injurious experience on which to draw upon. For example, where an injury occurs to a region of the body never before injured or damaged outside a discernable recall period, the player has no available measure to gauge the level of discomfort, if benchmark comfort has not been established. A perceived advantage of measuring multiple anatomical sites rather than an overall lower extremity comfort value is the capacity to monitor multiple anatomical sites at the same time. This approach offers a monitoring tool for adjacent regions when injury occurs. The case studies show how compensatory musculoskeletal function will occur when discomfort and injury affects the body. In the present study, lower extremity comfort variability was attributed to six segmental comfort regions providing an overall sum comfort score. The results provide the first insight into how the demands of elite football effects lower extremity comfort. High comfort was registered by players only 18% of all comfort recordings, while poor comfort was recorded 23% of occasions. Poor comfort was strongly correlated to injury (R^2 = 0.77) and high (blue zone) comfort had a weak correlation (R^2 = 0.15). The use of a tiered comfort system, poor (red), usual (black), and high (blue) zones further quantifies comfort data. Where a player falls into a comfort zone lower than the median range, the index acts as a warning system for both the player and the management team. The use of a median score for each player instead of an average score to determine zones provided a middle range score and was more accurate when data were non-normally distributed. A post-hoc analysis of all players indicated the median and range for zones was consistent with mean and standard deviation for majority of participants.

Usual (black zone) comfort as determined by median $^{\pm 1 \text{ comfort points}}$ enabled a 3 $^{\text{comfort point}}$ spread. This allowed for some variation within the zone of usual comfort as comfort variations occur due to pain stimuli via the neural networks of the body (Karoly, et al., 1987). A spread of $4^{\text{comfort points}}$ between poor (red zone) comfort and high (blue zone) comfort enabled the capture of extreme comfort values for each player.

The interpretation of the study data, suggests comfort does play a part in injury. Figure 5.1, highlights the spread of comfort and may represent the physiological adaptation of the lower extremity to the demands of professional football. Usual (black zone) comfort which was calculated as a 3 $^{\text{comfort points}}$ spread around the median may be representative of a theoretical comfort threshold required for individuals to avoid injury associated with lower extremity discomfort. This is an area of future research which was outside the scope of this study.

Of the 5033 collected events for 182 players usual (black zone) comfort accounted for 58.6% of all comfort events. Comfort scores greater than the median $^{\pm 1 \text{ comfort points}}$ resulted in no *time loss events* except for five outliers, however lower extremity scores less than the median range resulted in a significant number of *time loss events* (R^2 =0.77). This may indicate high comfort scores act as a protective mechanism against lower extremity injury, but poor (red zone) comfort does not. It is acknowledged this premise can only relate to non-contact injuries.

The incidence of injury, 65.8 injuries/1000^{hours} reported in this study was greater than some reported injuries in the rugby league, 44.9/1000^{hours} (Gibbs, 1993) and a ten year average in Australian Rules, 41.7/1000^{hours} (Orchard & Seward, 2008), but less than other studies involving rugby league 160.6 /1000^{hours}, (Gabbett, 2000) and rugby union 83.9/1000^{hours}, (Fuller, Laborde, Leather, & Molloy, 2008). However, different injury definitions and study designs will affect outcomes. The use of *time loss events* to describe non participation in full training (Drawer & Fuller, 2002; Hagglund, et al., 2009) may have inflated injury rates. The use of time loss to define injury is increasingly used in football studies because it takes account of injuries most likely to affect a player's health and performance (Chomiak, Junge, Peterson, & Dvorak, 2000). For this study, *time loss event* was defined as not being able to take part in a regular training session or match because non-participation was considered to affect performance outcomes. The premise for the effect of non training participation and performance is to be investigated by the authors as an extension of this study (Chapter 8).

The recording of *time loss events* to the knee and below were based on two criteria: the LLCI was not tested during development to include other anatomical locations such as the groin or hip and the inclusion of more areas would have created an index which was overly complicated, from a time to complete perspective. Moreover, the majority of injuries sustained in most running sports involve the anatomical segments used in this study (Chomiak, et al., 2000).

A perceived limitation of the LLCI was not including hamstring, groin, pelvic and back injury as a consequence of lower extremity comfort. A separate assessment of injuries sustained by one of the organizations participating in the study indicated that of 17 hamstring injuries sustained over a 30 week period, the LLCI was predictive of time loss hamstring events on 8 (47%) occasions. This snapshot of injury outside the parameters of the LLCI may provide some insight to pain inhibition responses. It is possible that hamstring injury was due to compensatory function for lower extremity discomfort. While supportive evidence exists for neurophysiologic compensatory theory, the effect of musculoskeletal discomfort at one anatomical segment being associated with injury at a different anatomical segment requires further investigation.

The capacity to use comfort in two ways, as a method to predict injury (Predicted ^{TLE}) or to categorize the extent of a known injury (Known ^{TLE}) by observing the comfort scores provides a mechanism to more capably manage an athlete in either a proactive sense (Predicted ^{TLE} = LLCI $^{\text{data pre injury}}$), or manage poor lower extremity discomfort when it is known (Known ^{TLE} = LLCI $^{\text{data post injury}}$). A *time loss event* initially labelled a Predicted ^{TLE} will become a Known ^{TLE} in subsequent weeks where a player does not return to regular training (Figure 5.10). Therefore, as *time loss events* in the study were a combination of Known ^{TLE} and Predicted

^{TLE}, the capacity of poor (red zone) comfort to predict injury was not statistically significant (R^2 =0.18). However, conclusions about the LLCI lacking face validity for injury prediction should not only be interpreted by statistical validity but also by clinical application. Figure 5.10 indicated for two new injury events in weeks 6 and 10; poor (red zone) comfort was predictive of injury (Predicted ^{TLE} = LLCI $^{data\ pre\ injury}$). For the entire study, on 47% of occasions, *time loss events* were predicted.

The football organisations involved in this study generally had good intervention programs, therefore many of the *time loss events* were Known ^{TLE}. The case study (Figure 5.9) was considered representative of a Known ^{TLE} which occurred in the study. In the example provided poor (red zone) comfort was used to not only assess the site of injury (shin), but also comfort levels of adjacent anatomical sites (foot, ankle, calf-Achilles, knee and footwear) due to the injury. Calf comfort reduced following shin injury. While there may be many reasons for a reduction in calf comfort, compensatory movement patterns and protective responses to unload the injured region are speculated. The use of a multi-segment lower extremity comfort measure provided a barometer to assess comfort for return to full training participation which did not occur until week 11. Further, the site of injury did not return to pre-injury comfort level for some weeks following the incident, which highlights the benefit of how prospective measures of comfort provides medical and conditioning staff with quantitative data to implement more targeted intervention programs.

In the study all *time loss events* were highly correlated with poor (red zone) comfort (R^2 = 0.77; $P<0.0001$). However, there were occasions where poor comfort had a weak correlation *time loss events* (R^2 = 0.16; $P<0.0001$). Where poor comfort was not associated with a *time loss event;* the group examined in the study was capable of full physical activity. This creates a dilemma for medical staff about how to manage the athlete. While player baseline comfort can be compared to comfort at the time of injury to enable quantification of the injured zone and adjacent anatomical segments not directly affected by injury, the study shows that where poor comfort is registered, there is a high correlation with injury. Thus, the challenge for the clinician is to process all available information, to enable an informed decision about the potential for injury with continued participation where poor lower extremity comfort is registered. The use of lower extremity comfort scores may offer one additional method of assisting with decision making.

5.6 CONCLUSIONS

The LLCI was developed to provide a tool for clinicians and athletes to monitor lower extremity comfort at multiple anatomical regions. The registering of lower extremity comfort scores using the LLCI provides a series of signposts for players and medical staff which contribute to the injury management paradigm. A method to monitor lower extremity health prospectively as well as assisting with decision making when injury occurs is offered by implementing the LLCI.

The application of the comfort zones provides both health professional and footballer with the knowledge that an unacceptable lower extremity comfort score is a LLCI score of two comfort points less than median comfort, which can be visually shown as a red zone. This zone is associated with injury. The comfort index has high face and criterion-related validity as a clinical tool with which to measure the lower extremity well-being of players. By quantifying lower extremity comfort into high, usual and poor comfort zones, the study was capable of identifying the role of lower extremity comfort on injury in three elite codes of football regularly played in Australia.

The monitoring of lower extremity comfort data as one entity as well as individual anatomical segments offers a comprehensive overview of lower extremity health status for football and may be used to assist with rehabilitation strategies and return to activity plans by quantifying comfort. The main advantages of the LLCI are its ease of implementation, the clarity of the information collected and most importantly, the direct clinical application of the information to the performance of individual players. The categorisation of players into high and low injury risk groups for any given Weekday or Match-day training based upon lower extremity comfort will facilitate critical clinical decisions about rehabilitation, medical interventions and training loads. Such decisions are likely to have a major influence on the reduction of injury events and on player performance.

CHAPTER SIX

EFFECTS OF FOOTWEAR ON COMFORT AND INJURY IN PROFESSIONAL FOOTBALL

This chapter is supported by the publication:

Kinchington, M., Ball, K., Naughton, G. (in press). Effects of footwear on comfort and injury in professional football (Rugby League). Journal of Sports Sciences.

6.1 ABSTRACT

Background: Footwear in a simplistic role is intended to protect the foot from the environment and provide traction. Footwear may also be used as an instrument of injury management. This study examines the role of a tailored footwear program in professional football as a mechanism to assist injury management.

Objectives: Contribute to the lower extremity injury paradigm by examining the association between footwear and poor comfort and injury. Specifically, the aim of this study was to examine the effectiveness of a tailored footwear program on lower extremity comfort in professional rugby league players.

Methods: The study was conducted over 30 weeks and involved two professional football teams, (N = 59), from the Australian National Rugby League competition. One team was assigned to a footwear program (intervention), while players from the control group continued usual practices of self-selected footwear. Independent t-tests were used to compare comfort events between the two study groups and obtain a mean difference and 95% confidence interval (95% CI) as an estimate of effect size. Box plots were used to graphically compare outcomes between groups. Injury prevalence was calculated as the number of injuries per 1000^{hours} of player exposure and injury was defined as *time loss events.*

Results: A tailored footwear program resulted in a lower incidence of injury and higher lower extremity comfort ratings. The intervention group had fewer lower limb injuries (P=0.005; Cohen *d* = 0.72) and higher comfort ratings (P<0.001, Cohen *d* =1.24) than the control group. Specifically, the intervention group reported a lower incidence of poor comfort events (mean = 3.8, SD = 2.7) than the control group (mean = 7.9, SD = 3.7). Observations also included fewer *time loss events* in the intervention (mean = 6.3, SD = 4.8) than the control group (mean =11.0, SD = 6.3) and reduced injuries/1000^{hours} in the intervention (24.79/1000^{hours}) than the control group (30.76/1000^{hours}).

Conclusions: A tailored footwear program consisting of player education, prescription, modification and monitoring of footwear reduced lower extremity injury and improved comfort levels. These findings will be useful to medical advisers involved in other running-based team sports who can now consider adding footwear comfort as a possible contributor to injury prevention.

6.2 INTRODUCTION

Lower extremity injuries are associated with a large number of intrinsic and extrinsic factors that affect musculoskeletal load and tolerance (Bahr & Krosshaug, 2005). Injury causes and intervention strategies are multi-factorial and complex. They require constant appraisal and revision (Van Mechelen, et al., 1992). The study here-in was designed to contribute to the lower-limb injury paradigm by examining the association between footwear and lower-limb comfort and whether a relationship existed between poor comfort and injury. The study was conducted among professional footballers and involved two professional rugby league teams participating in the National Rugby League (NRL) competition.

Rugby League is essentially a collision sport resulting in musculoskeletal injury of a contact nature (King, et al., 2010). Injuries are more common in lower rather than upper limbs in the rugby codes (Gissane, Jennings, Kerr and White, 2002; Brooks, Fuller, Kemp and Reddin, 2008), and are similar to injuries reported in other football codes (Hoskins, Pollard, Hough, & Tully, 2006). Because lower-limb injury has been associated with foot-leg geometry (Cowan, et al., 1996; Hreljac, et al., 2000; Kaufman, Brodine, Shaffer, Johnson, & Cullison, 1999), football boots of varying designs may contribute to injury (Bentley, Ramanathan, Arnold, Wang, & Abboud, 2010; Grund, Senner, & Grube, 2007; Villwock, Meyer, Powell, Fouty, & Haut, 2009).

Conditioning and preparation in the rugby codes requires extensive hours of training in the form of multidirectional and intermittent running drills. For most professional teams in the rugby codes, training represents 80% of field activity and 20% of match time. A common breakdown of training, in the rugby codes, has been estimated to range between six and nine hours (Brooks, Fuller, Kemp and Reddin, 2008) and match time less than 90 minutes (Brewer & Davis, 1995). Thus, the type of shoe selected for training might be considered of greater importance than match-day footwear. While such a theory may be reasonable within football, no studies have examined the impact of regulated footwear guidelines on lower-limb comfort or injury in football.

Important footwear characteristics for injury prevention include traction, cushioning, fit, and suitability relative to task as well as lower-limb morphology (Kinchington, 2003; Lake, 2000). An optimal footwear condition would require shoes to be comfortable and decrease injury by reducing muscle activity (Nigg, 2001). Studies of military populations (Mündermann, et al., 2003a) basketball players (McKay, Goldie, Payne, & Oakes, 2001) walkers (Morio, Lake, Gueguen, Rao, & Baly, 2009) and runners (Kleindienst, Bruggemann, Krabbe, & Walther, 2003) indicate footwear can influence the incidence of injury. However, research into footwear within the rugby codes lacks development (Milburn & Barry, 1998). Therefore, the aim of this study was to examine the role of footwear on lower-limb comfort and resultant injury by comparing lower-limb comfort differences in a control and intervention group of rugby league players.

6.3 METHODS

Two National Rugby League (NRL) teams were recruited for a prospective study. The study was conducted over 30 weeks that included four weeks of pre-season training and 26 weeks of competition. Letters of support were obtained from the respective football organizations. Ethics approval was granted from the Human Ethics Committee at Victoria University, Australia.

Two football teams from the same competition were assigned either to the control or intervention group. The teams were allocated at random. Because six players discontinued, the study concluded with 32 players in the intervention group and 27 in the control group. The respective teams participating in the study were based in the same geographical location, commonly shared the same football ground for competitive matches and shared many of the same training practices common to professional rugby league teams participating in the NRL.

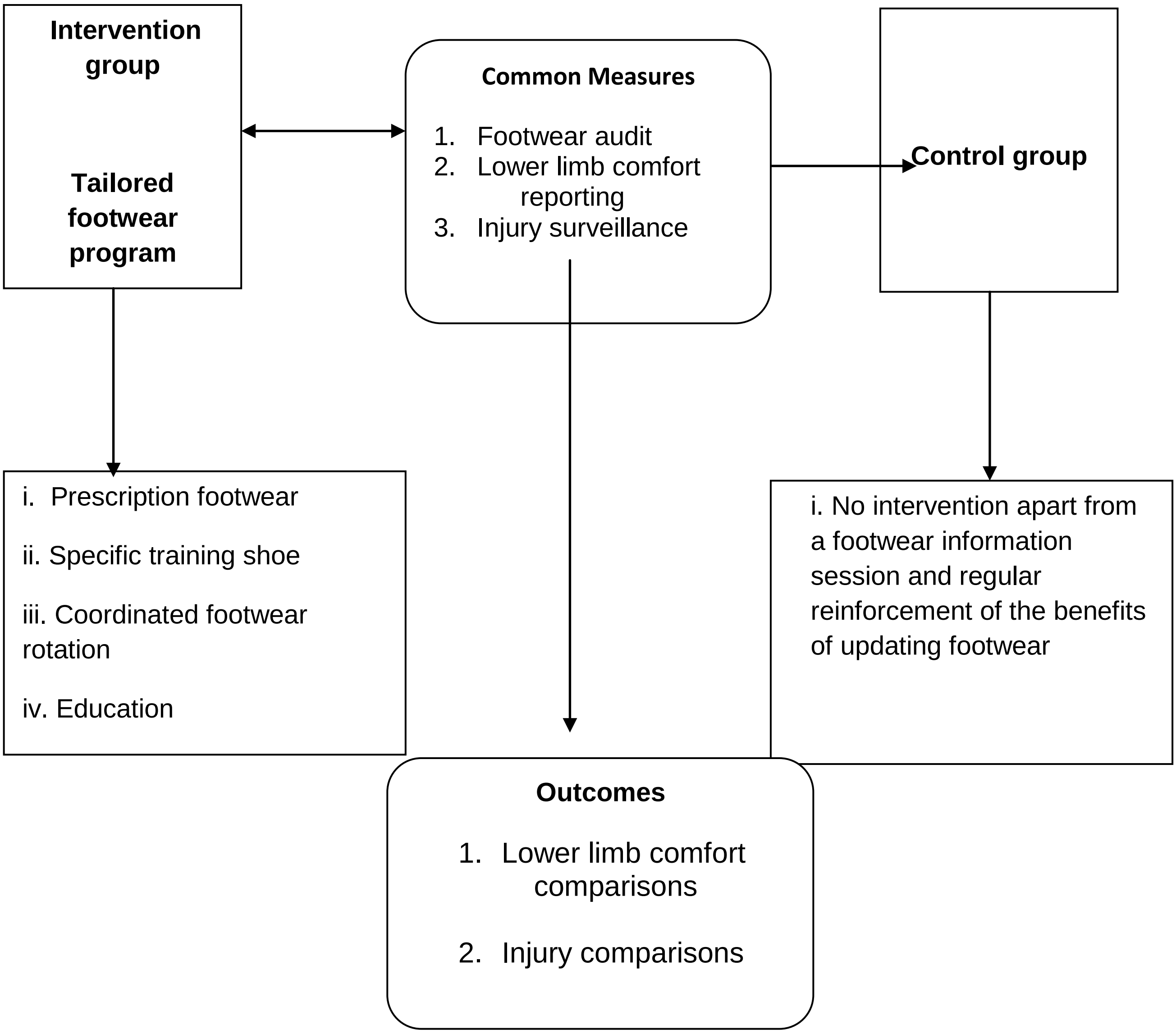
The intervention team used a "tailored footwear program". Facets of the program involved:

I. Use of turf shoes for all training sessions rather than football boots;
II. Individual prescription athletic, football and other footwear for all training and Match-day conditions;
III. Frequent rotation of footwear;
IV. Player and staff education.

For the intervention group, footwear was prescribed by a screening of players by a qualified podiatrist. It was the responsibility of the player to have four styles of shoe available at all training and Match-day events. Usually, players obtained footwear either from retail outlets or via player managers with sponsorship arrangements. Footwear was examined by a podiatrist at six weekly intervals and more often if a player reported either lower extremity discomfort or sustained injury. Shoes were examined for task suitability, excessive signs of wear, and comfort. When necessary, recommendations were made to the players to change footwear. The Football Department adopted a policy of "non appropriate footwear-no train policy" to improve player compliance.

The control team did not access the intervention footwear program. Players used existing practices of self-footwear selection. However, a footwear awareness session informed players, coaches and staff about the perceived benefits of a designated training / turf shoe for field-based training activities before the study commenced. The recommendation was for each player to have four styles of footwear available at all training and Match-day events. The footwear available for use included firm and soft ground football boots, turf shoes and athletic footwear. Footwear used by players in the control group was reviewed at six-week intervals. General advice to frequently update footwear to new versions and the need to have different styles of footwear available for use for training sessions was reinforced.

Figure 6.1 *Intervention v Control group*



6.3.1 Collection of data

6.3.1.1 Lower extremity comfort

Prospective lower extremity comfort was recorded for all players during the study using the previously validated Lower Limb Comfort Index (LLCI), detailed in Chapters 3 and 4; (Kinchington, et al., 2010). Lower extremity comfort zones for each player were established using criteria previously described (Chapters 3-5). Three comfort zones were established by calculating the sum of six lower-limb anatomical sites and using the median of lower-limb sum scores to set baseline comfort for each individual. Each zone was apportioned an arbitrary colour to reflect comfort: Red zone represented poor comfort (median comfort $^{-2\text{ comfort points}}$). Black zone was associated with median or usual comfort (median $^{\pm1\text{ comfort points}}$) and blue zone was a measure of high comfort (median $^{+2\text{ comfort points}}$). The apportioning of upper and lower zones was established by trials using other scores above and below the median.

Data were collected at football club premises in an environment familiar to players. Data collection occurred at the same time each week, which represented 24-36 hours after Match-day. The data represented 30 weeks (180-200 hours) of training and match exposure per player.

6.3.1.2 Injury data collection

Injury surveillance data were collected by the teams’ fitness and medical staff of respective organizations. A “time loss” definition applied to a missed training session or match. If a ‘medical attention event’ did not result in a missed training or Match-day participation, it was not recorded (Hagglund, Waldén, Bahr, & Ekstrand, 2005).

6.3.1.3 Footwear data collection

The recording of footwear type at the main training sessions (one to two sessions per week) was completed either by players who logged information onto a worksheet before entering the training field or a researcher who entered the data during the training session.

6.3.2 Statistical analysis

Data were analysed using SPPS version 15.0. An alpha level of $P < 0.05$ was considered significant. Independent t-tests compared comfort events between the two study groups and obtain a mean difference and 95% confidence interval (95% CI) calculated effect size. Independent t-tests are robust to non-normality (skewness <-1 or skewness>1) and were used when there were no influential outliers. In addition, effect size between group means for comfort and injury data were calculated using Cohen *d*. Where outliers were apparent and data were not normally distributed (Peat and Barton, 2005), a non-parametric Wilcoxon signed ranks test was used to validate the parametric statistic and to confirm that the P value was not over-estimated (Altman and Dore, 1990). To display results graphically, box plots were used to compare outcomes between groups. Injury prevalence was calculated as the number of injuries per 1000 hours of player exposure (Hagglund, Walden, Bahr, and Ekstrand, 2005).

6.4 RESULTS

6.4.1 Description of cohort

At baseline, players were well matched for age, stature and body mass (Table 6.1). Of the 65 footballers recruited, six were excluded from the final analysis. In the intervention group, two players were downgraded from the NRL competition, and one suffered a season-ending injury during a trial game. One player in the control group sustained long-term injury early in the study, and two failed to enter data appropriately. Therefore, data were analysed for 59 players who recorded 1540 comfort readings for the period of the study / weeks (mean = 26.1, SD= 0.5).

Table 6.1 *Description of players within the research project*

	Intervention group (N=32)	**Control group (N=27)**
Age [years]; mean (SD)	23.4 (2.9)	24.2 (3.2)
Height [cm]; mean (SD)	185.8 (5.0)	184 (6.0)
Mass [kg]; mean (SD)	98.50 (7.7)	97.20 (10.0)
Professional football experience	7 (rookies) 22 (mid tier) 3 (veterans)	8 (rookies) 16 (mid tier) 3 (veterans)

6.4.2 Comfort differences between control v intervention group

Comparisons were made between the groups for comfort. Overall, the control group had more poor (red zone) comfort events indicating lower comfort than the intervention group. Table 6.2 shows the differences between the two groups for lower extremity comfort outcomes. Poor (red zone) comfort for the control group expressed as a percentage was approximately twice that of the intervention group (29.6% v 14.6%), indicating lower rates of comfort for more players in the control group. The footballers in the intervention group registered more usual (black zone) comfort events (63.7%) than control group players. Each player from the football team exposed to the tailored footwear program, recorded only 3.8 (14.6%), poor (red zone) comfort events. High (blue zone) comfort was not different between the groups (P=0.28), intervention players registering high (blue zone) comfort events 20% of occasions. Control participants registered high comfort 25% of the time.

Table 6.2 *Lower extremity comfort results for intervention and control groups*

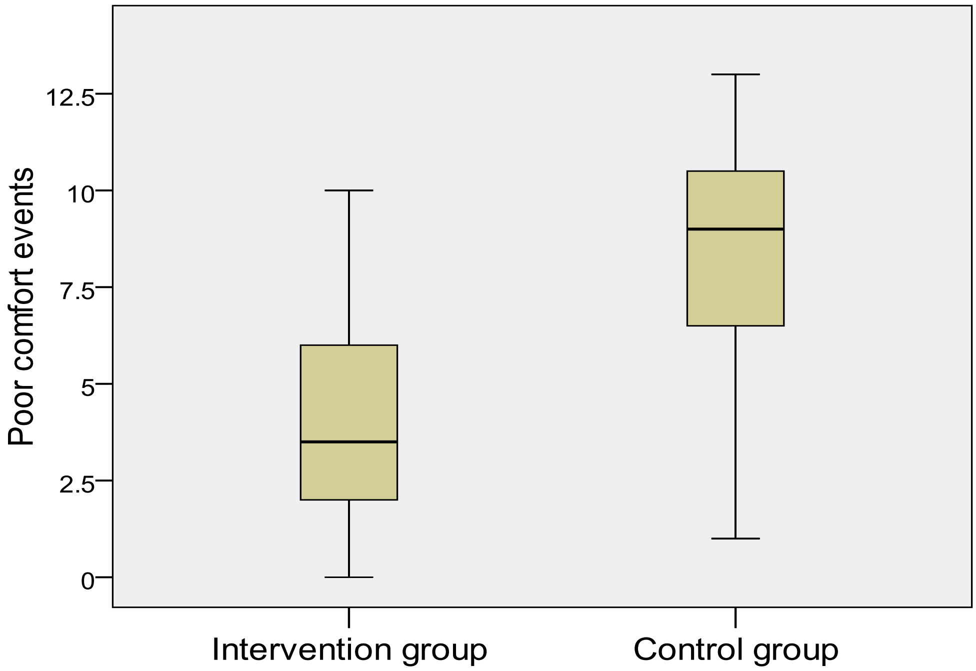
	Intervention group	Control group	Mean difference (95% CI)*	P value[1] (Cohen *d*)
Poor comfort events (red zone)	3.8 (2.7)	7.9 (3.7)	-4.1 (-5.8, -2.4)	<0.0001 (1.24)
% poor comfort	14.6 (10.7)	29.6 (11.8)	-15.0 (-20.8, -9.1)	<0.0001
Usual comfort events (black zone)	16.8 (4.5)	11.4 (4.6)	5.4 (3.0, 7.8)	<0.0001 (1.18)
% usual comfort	63.7 (15.4)	45.9 (17.0)	17.8 (9.4, 26.3)	<0.0001
High comfort events (blue zone)	5.7 (2.8)	6.6 (3.6)	-0.9 (-2.6, 0.8)	0.28 (0.28)
% high comfort	21.7 (10.7)	24.6 (11.9)	-2.9 (-8.8, 3.0)	0.33

** A positive value favours the Intervention group; a negative value favours the Control group*

[1] Parametric P value using independent samples t-test

The between group differences in lower extremity comfort scores is shown by the box plots (Figures 6.2, 6.3, 6.4). Figure 6.2 shows poor (red zone) comfort was higher (median nine events) in the group who did not access the tailored footwear program compared to the intervention group (median three events).

Figure 6.2 *Poor comfort (red zone) differences between the intervention and control group (P<0.0001)*



The range of poor comfort for the control group players was one to 13 comfort events, compared with zero to ten events for the intervention group. The narrow ranges (three to six events) for 50% of poor comfort scores for the intervention group indicated the tailored footwear program might have influenced lower extremity comfort. For the control group, using existing footwear practices, poor comfort range was greater and more frequent than the intervention group.

Usual comfort (Figure 6.3) was higher for the intervention group with 50% of the scores lying in range 14 to 20 events than 6 to 14 events for the control group. The median value for high comfort (Figure 6.4) was the same for both groups (6 events) with some of the control group displaying higher comfort scores than the intervention group. The upper 25% range in the control group for high comfort was 9 to 14 events and was greater than the 8 to 11 events recorded for the intervention group.

Figure 6.3 *Usual (black zone) comfort differences between the intervention and control group (P<0.0001)*

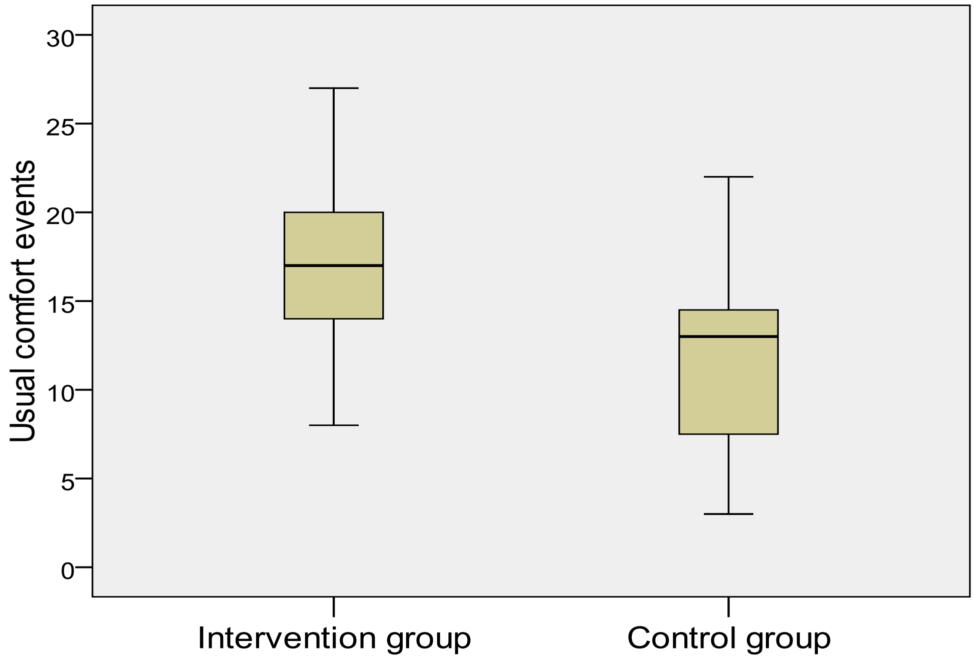
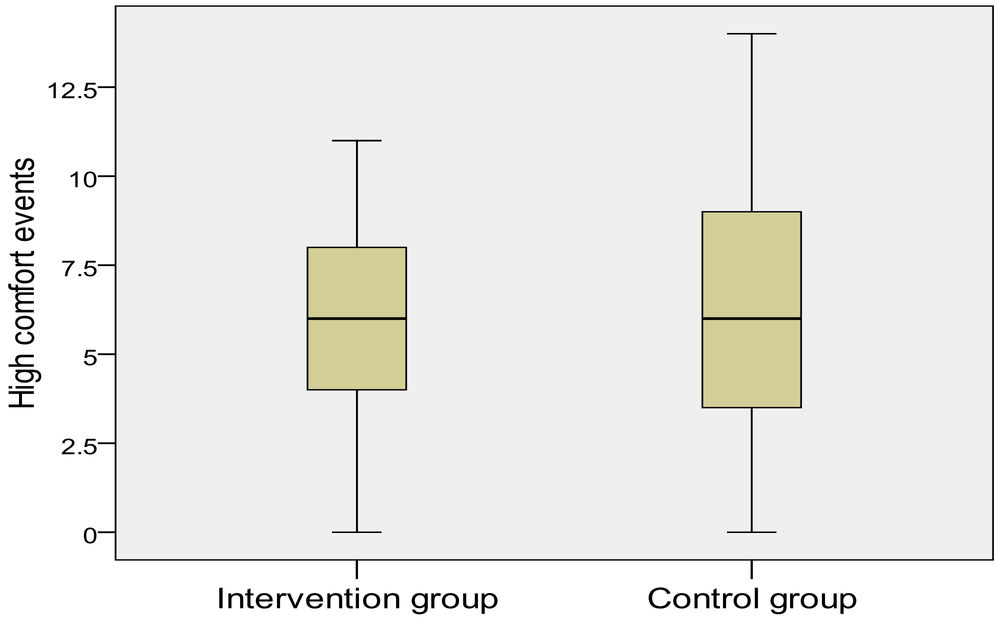


Figure 6.4 *High comfort (blue zone) differences between the intervention and control group (P=0.28)*



The comfort results indicate a tailored footwear program may be protective for footballers against poor lower extremity comfort and might have consequences for injury outcomes.

6.4.3 Injury outcome data for control v intervention group

The overall, injury rate was 25.32/1000^{hours} (95% CI 21.40 - 29.25/1000 ^{hours}) for both groups. The total incidence of injury events associated with the lower extremity was 156 over the period of the study (mean = 2.64, SD= 1.8). Table 6.3 shows injury statistics for both groups to profile overall injuries and to investigate differences between the groups.

The intervention group had fewer injuries per 1000/ ^{hours}, 24.79 (mean = 2.2, SD = 1.7 injury events) compared with 30.76 injuries/1000 ^{hours} (mean = 3.2, SD = 1.9 injury events) for the footballers in the control group (P=0.03; Cohen *d* =0.56). Figure 6.5, illustrates the middle data for the control group had a wider range (two to five) of injury events than the intervention group (one to three). The results show that footballers who use existing self-selection footwear strategies sustained more injury exposures than players who have a tailored footwear program.

The number of missed sessions was also less for the intervention group (mean = 6.3, SD = 4.8) than the control group (mean = 11.0, SD = 6.3), P= 0.005 and Cohen *d* = 0.72 (Table 6.3 and Figure 6.6). More specifically, training *time loss events* for the control group was higher (mean = 9.4, SD = 5.9) than the intervention group (mean = 5.3, SD = 3.6), P= 0.0003 with a high effect size for differences between the groups (Cohen *d* = 0.83). Match-day *time loss events* did not differ between the two groups (P=0.27, Cohen *d* = 0.37).

The between-group differences highlight the extent of training time loss was 44% higher for the control group than the intervention group. Although the Match-day time loss between groups was not different, the control group missed 0.6 (95% CI 0.5-1.6) games per player more than the intervention group. This translated to more than 15 match *time loss events* over 26 competition rounds.

The differential between the groups for non-contact time loss was significant ($P<0.0001$). Footballers in the control group (mean = 8.4, SD = 5.7) sustained three times more non-contact *time loss events* than the intervention group (mean = 2.7, SD = 2.9), which was significant ($P<0.0001$; Cohen d = 1.03), Table 6.3. The range for the control group was 18 *time loss events* compared with nine for the intervention group (Figure 6.5). The intervention group players sustained more contact *time loss events* (3.5 v 2.6; P=0.05). This result might have precluded the intervention group from experiencing more non-contact events; however this was unlikely because the mean difference between the groups for contact *time loss events* was a negligible 1.1 events.

Table 6.3 *Time loss events as injury prevalence, missed training and Match-day events and mechanism of injury.*

	Intervention group N=32	**Control group** N=27	**Mean difference (95% CI)***	**P value[1]** (Cohen *d*)	**P value[2]** (Cohen *d*)
Injury Prevalence	2.2 (1.7)	3.2 (1.9)	-1.0 (-1.9, -0.1)	0.03 (0.56)	
Missed sessions total	6.3 (4.8)	11.0 (6.3)	-4.3 (-7.2, -1.4)	0.005 (0.72)	
Missed training	5.3 (3.6)	9.4 (5.9)	-4.2 (-6.8, -1.5)	0.003 (0.83)	
Missed matches	1.0 (1.9)	1.6 (2.1)	-0.6 (-1.6, 0.5)	-	0.27 (0.37)
Non-contact *time loss events*	2.7 (2.9)	8.4 (5.7)	-5.6 (-8.1, -3.1)	<0.0001 (1.03)	
Contact *time loss events*	3.5 (3.8)	2.6 (4.6)	1.1 (-1.2, 3.1)	-	0.05 (-0.22)

** a positive value favours Intervention group, a negative value favours Control group*

1 Parametric P value using independent samples t-test

2 Non-parametric P value using Wilcoxon signed ranks test

Figure 6.5 *Injury by prevalence highlighting differences between the intervention and control group (P<0.03)*

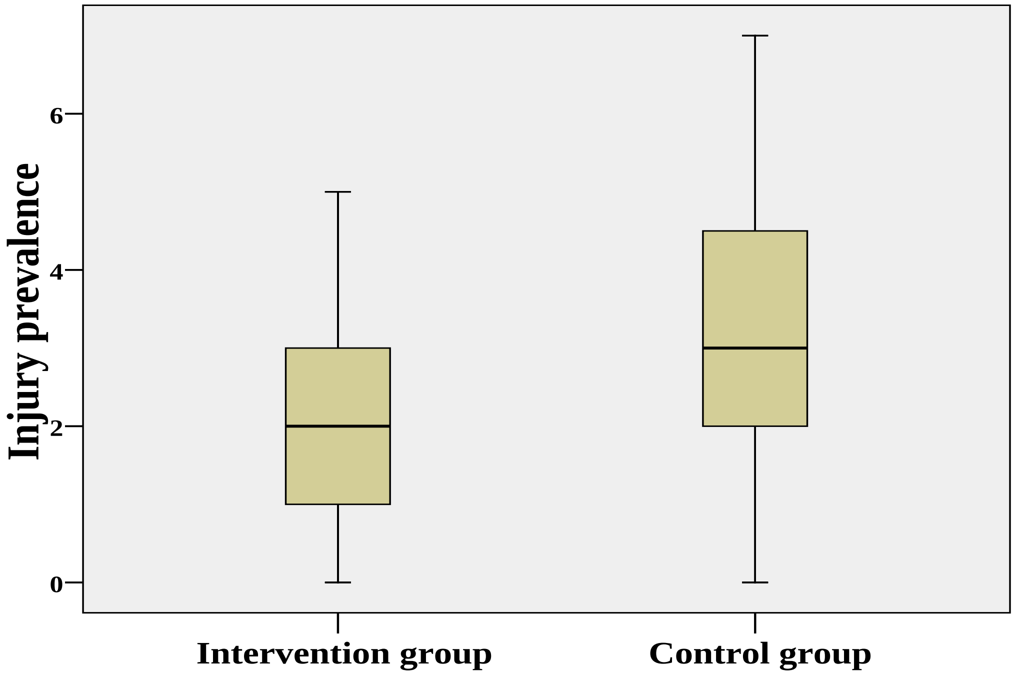


Figure 6.6 *Time loss events training and match event (SD) for intervention and control group showing between group differences (P<0.005)*

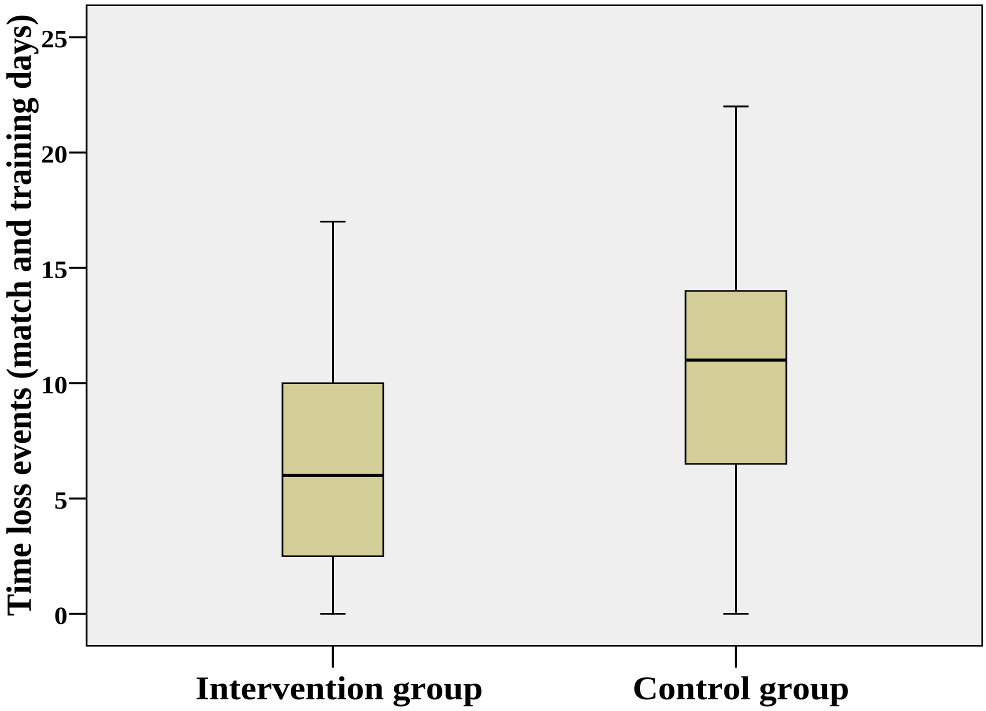
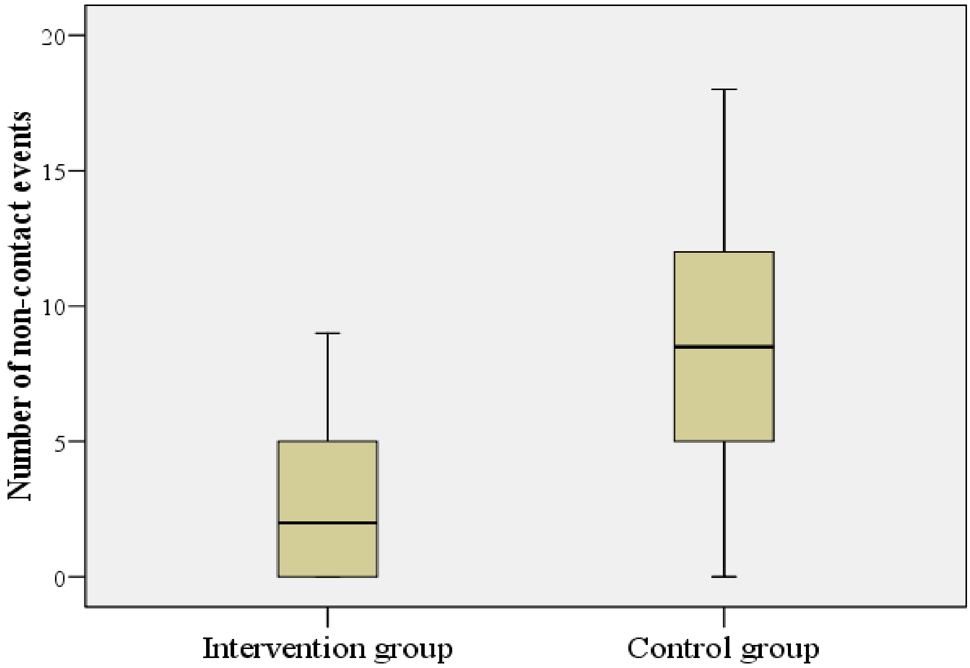


__Figure 6.7__ Non contact time loss events for Intervention and Control groups (P<0.0001)



6.4.4 Footwear

Footwear data were collected for both clubs for each week of the study. The breakdown of footwear was turf shoes (56.8%), boots (38.1%) and other footwear such as athletic joggers (5.1%) for the1540 collected events. New footwear was used by every player in the intervention group and only 15% in the control group. For collected Match-day events (1260 collections when adjusted for injury and missed data), a cleated stud configuration (45.6%) was the most commonly used footwear, followed by rounded-moulded studs (33%) and screw-in (non plastic studs) for 21% of Match-day wear time. For Match-days, all players from both groups used football boots exclusively. Turf shoes were not used during matches except for one player who used a turf shoe on one foot and a moulded-cleated boot on the other foot. Soft ground footwear (screw-in studs) was used on 15% of occasions. However, screw in-studs were used more frequently by the control group (45%) than the intervention group (3%). No difference was observed between the groups for firm ground boots (cleated and moulded design). Cleated style boots (62%) were more common used than moulded style boots, which is consistent with modern trends in footwear styles.

Compliance for turf shoe usage in the intervention group was 96% over the testing period when adjusted for injuries in which athletic footwear was used as the recommended rehabilitation shoe. The turf shoe usage in the intervention group was high (mean = 22.2, SD = 2.2), with a range of 20-27 weeks. In the control group, turf shoes were used 15% over the test period, with turf shoe usage (mean = 4.0, SD = 7.1; range = 0-23 weeks). In the intervention group, all players (100%) used turf shoes for training at some stage during the study, while in the control group, 29% of players used turf shoes for some of the period.

Within the intervention group, football boots were changed at week 12 (90% of group), week 18 (20% of group) and week 24 (70% of group). Because turf shoes are more structured in the design and strength of materials than football boots, they were changed for all players at week 12. Other footwear rotations occurred on a needs basis due to injury or lost footwear. Soft ground boots (screw-in) did not change because usage for both training and Match-day ranged from zero (28 players) to five (one player) occasions and consequently, were rarely used.

The control group lacked a co-coordinated rotation system. However, general advice was given to each player at regular intervals and only 15% of players changed footwear to a new boot. Football boot rotation occurred for two players only during the test period, which was due to a change in sponsorship. Three players (11%) in the control group used football boots from the previous season. Only four players

(15%) had both firm ground and soft ground boots and they reported "never" or "rarely" having more than one football boot available on Match-day.

6.5 DISCUSSION

A tailored footwear program was associated with better lower extremity comfort and a reduced incidence of injury in a cohort of professional NRL players. The environment for testing within two professional football organisations was unique however, the results are thought apply to other sports.

6.5.1 Comfort and injury

The difference between the study groups was significant for both comfort and injury. Injury data show prevalence for injury (25.32/1000^{hours}; 95% CI 21.40 - 29.25/1000 ^{hours}) was less than the range for other Rugby League studies of 44.9 / 1000 ^{hours} (Gibbs, 1993) to 271.1 / 1000 playing ^{hours} (Gabbett, Minbashian, & Finch, 2007). However, this study only evaluated lower extremity injury, while other studies included injury from all body regions as well as recording all ailments without time loss injury (King, et al., 2010). Therefore comparisons of non-contact lower extremity injury reports within the same code are problematic.

The low number of overall high-comfort events in the study was speculated to be attributable to the demands of professional rugby league. A surprising anomaly in the results was that control group players recorded 0.8 more high (blue zone) comfort than intervention group players, although it was not statistically significant (5.7 v 6.6; P=0.28, Cohen *d* = 0.28). This may be explained by fluctuations in comfort where a player records extreme (high or low) comfort readings. It would be expected that during a period of injury rehabilitation and on return to full training, lower extremity comfort would improve and thus be recorded as a high comfort score. Given that the control group players had more *time loss events* than intervention players; there were more occasions for comfort levels to re-establish.

The effect of *time loss events* for training is considered to have a detrimental effect on football skills, fitness and potentially limits player selection. The results of this study show the control group football preparation was compromised by reduced lower extremity comfort resulting in more missed training sessions. End of season competition tables in the NRL for the period of the study indicated the control group did not participate in finals and finished the season in the last quartile of all the teams in the NRL. Although speculative, the results suggest an ecological association between comfort, injury and performance. Despite acknowledging many factors will effect competition standings, this study may provide a basis to further explore the effect of comfort parameters on performance.

6.5.2 Footwear

The dependent variable in this study was lower extremity comfort under two different conditions of professional advice. The use of professional advice involved tailored footwear prescription, education, footwear rotation, and the use of a designated training shoe. The football boot in the simplistic form is intended to protect the foot from the environment and provide adequate traction. For elite performances, it is generally accepted that a range of shoes should be made available to suit varying ground (hard vs. soft), environmental conditions (dry vs wet), and training routines (running vs. skills). However, footwear styles across a spectrum of sports have been associated with comfort effects (Mundermann, et al., 2001), injury (Kinchington, 2003) and performance (Nigg & Wakeling, 2001). This study is the first experimental field based research involving footwear in professional or amateur football.

Differences in footwear practices between the two football teams were considered a major finding from this study. Differences were observed despite both teams using the same football venue for matches and training in a similar geographic region and under the same climatic conditions. Because footwear has been identified as an important criterion in injury management and prevention, the use of specific footwear based on lower extremity assessment was considered vital to the outcome results obtained in this study. This can be demonstrated by the non-contact injury data results. Contact injuries are considered unavoidable within the rules of fair-play, while non-contact injuries are modifiable. Although speculative, due to many variables which contribute to injury, the significant ($P<0.0001$, Cohen $d = 1.03$) non-contact *time loss events* sustained by footballers in the control group might have been due to the ad-hoc footwear practices adopted by the group. Conversely, a coordinated footwear program might be protective against non-contact injury.

A high compliance in training shoe use may have also contributed to lower poor comfort and reduced injury within the intervention group. Players used the recommended shoe for a mean of approximately 22 of the possible 30 training weeks. Most likely reasons for non-use of turf shoes included training shoe not available, training surface not suitable to use of turf shoes due to weather conditions or turf shoe in a state of disrepair, awaiting replacement, or simply non compliance.

In the control group, the use of a training-turf shoe was poor. Only 18% of players used turf shoes on an average of three occasions. Reasons given for non-use of a designated training shoe included shoes perceived as heavier and bulkier than a football boot, beliefs that turf shoes affected kicking and lacked traction, and a philosophy of “need to train as you play”.

The intervention group used soft ground (screw-in) footwear less frequently than the control group. This occurred despite the match fixtures of the intervention group comprising more evening-night games than the control group, at which it would be expected ground surfaces would be more slippery.
In the control group, soft ground football boots were used by 12 players (44%) for a total of 124 training weeks. Eight players used soft ground football boots on a regular basis. An intra-group comparison among players who used soft ground boots and others, did not indicate any differences for comfort or *time loss events*. In the intervention group, screw-in studs were selected by three players for a total of 19 training weeks. As climate and environmental factors were similar in both groups, the use of soft ground footwear for training was accepted as the habitual training routine for control and intervention players.

Players from the intervention group responded positively to the footwear program. It is postulated player footwear habits in the intervention group were altered by factors such as the footwear education program that provided constant reminders to players, the strategic placement of posters around the training facilities and support from coaching and conditioning staff.

Studies of footwear biomechanics and sports physiology indicate footwear can positively influence joint and muscle load (Tine, Witvrouw, De Cock, & De Clercq, 2005), improve oxygen expenditure (Saetran & Norstud, 2008), and improve performance (Nurse, Hulliger, Wakeling, Nigg, & Stefanyshyn, 2005; Wakeling, et al., 2002). This study provided an insight to the effect of footwear in professional football.

It is postulated that the cumulative effect of football boot usage had a detrimental, effect on the musculoskeletal system in the capacity for footwear to attenuate load and promote stability, thereby challenging comfort mechanisms. However, conclusions about the effect of specific footwear selections on comfort and time loss results should be interpreted with caution as outcomes are multifactorial.

Factors beyond the scope of this study included; differences in training venues (grass type), training philosophies and methods, different football team cultures, motivational status, readiness to listen and act, and the resources of a football club. The intervention group organisation was considered a more financially viable and successful (on-field results) club than the control group. Although this was difficult to quantify, better resources may have imposed a strong influence on player footwear selection and overall lower extremity comfort. Also in the intervention group, footwear recommendations and interventions were strongly endorsed and reinforced by club management while players in the control group did not have the same amount of strategic support.

6.6 CONCLUSIONS

Using prospectively recorded data, this footwear intervention study found that a tailored footwear program consisting of player education, prescription of footwear, monitoring of footwear and footwear modification, substantially reduced lower extremity injury and improved comfort levels. Many variables are associated with footwear prescription and include surface conditions, player load forces, lower extremity biomechanics and comfort perceptions about footwear. Subsequently, it is difficult to generalise about the appropriateness of football boots. However, results showed a coordinated footwear program can be beneficial in the injury management paradigm. Ultimately, optimal footwear selection based on player comfort guidelines can be developed and may assist injury prevention strategies. It is likely that the results of this study are applicable to other professional and amateur sports, as footwear is germane to weight bearing sports.

CHAPTER SEVEN

AN INVESTIGATION INTO THE ROLE OF A FOOTWEAR INTERVENTION PROGRAM FOR PROFESSIONAL FOOTBALLERS. AN INTRA-CLUB CONTROL AND INTERVENTION STUDY.

This chapter is supported by the publication:

Kinchington, M., Ball, K., Naughton, G. (in press). An investigation into the role of a footwear intervention program for professional footballers. an intra-club control and intervention study. Gazzetta Medica Italiana.

7.1 ABSTRACT

Aims: Footwear comfort has been shown to affect musculoskeletal comfort and injury. The purpose of the study was to examine the role of footwear in the football environment between two groups at an intra-club level. The hypothesis for the study was the use of a turf shoe for rugby league training results improved lower extremity comfort compared to training in a conventional football boot.

Methods: Aspects of lower extremity comfort associated with footwear were examined in a cohort of National Rugby League players (N=53) from one club over one season. The design of the study was a non-randomised clinical trial. Using a participant preference method, two groups were formed. An intervention group used a designated style of training shoe over the season and a control group used a regular football boot.

Results: A designated style of training shoe had benefits when lower extremity comfort was compared between the intervention and control groups ($P<0.0001$), sustained fewer *time loss events*, mean 1.7 (SD 1.2) v 3.9 (SD 1.5), and players participated in more training sessions (P<0.0001, Cohen d= 1.59) and matches (P= 0.002, Cohen d= 0.83).

Conclusions: These results indicate a designated training shoe may have protective qualities for the lower extremity and has the capacity as an instrument of a tailored footwear program to aid the lower extremity comfort of footballers.

7.2 INTRODUCTION

Lower extremity injuries are associated with a large number of intrinsic and extrinsic factors that affect musculoskeletal load and tolerance (Bahr & Krosshaug, 2005). No one, isolated factor dominates the lower extremity injury paradigm and no one intervention is a panacea for management of injury. Rather, injury causes and intervention strategies are multi-factorial, complicated, and require constant appraisal and revision. Previous studies of football codes have identified various factors associated with lower extremity injury (Hagglund, et al., 2005; Hoskins, et al., 2006; King, et al., 2010; Orchard & Seward, 2008).

Footwear has been identified in the literature as an intervention strategy to improve lower extremity comfort (Anderson, Stefanyshyn, & Nigg, 2005; Hong, et al., 2005). Footwear is also an instrument to assist with reduction of musculoskeletal injury (Butler, Davis, & Hamill, 2005; Lake, 2000; Luo, Stergiou, Worobets, Nigg, & Stefanyshyn, 2009). A theoretical basis exists for the role of football boots in injury reduction (Bartold, 1999; Milburn & Barry, 1998), although corroborative research is not substantive.

Rugby League is a dominant code of football played at the professional level in Australia, United Kingdom and New Zealand. In a worldwide competition held in 2008, more than 60 countries participated. The game of Rugby League is a high intensity, intermittent, contact sport. Commonly an elite rugby league player will cover in excess of ten kilometres per game (Gabbett, King, & Jenkins, 2008) of jogging in a forward and backward direction, interspersed by periods of rapid acceleration and cutting manoeuvres (Gabbett, et al., 2008). Thus, footwear is essential equipment that can be beneficial to an individual in terms of comfort and preventing or managing injury. Conversely, inappropriate footwear can deleteriously alter lower extremity movement patterns culminating in injury (Kinchington, 2003; Shorten & Mientjes, 2003). Chapter 6 of this thesis identified the benefits associated with a dedicated footwear program on outcome measures, comfort and injury. The results showed a group which adopted a specific footwear program consisting of: (i) the dedicated use of a training shoe, as opposed to a football boot; (ii) the individual prescription of athletic footwear; (iii) the frequent rotation of footwear; resulted in higher lower extremity comfort ($P<0.001$), less *time loss events* from training and matches (6.3,SD 4.8) versus control group (11.0, SD 6.3) and reduced injuries/1000^{hours} (intervention 24.79, control 30.76). The study design was a prospective inter-club examination and therefore was limited by not controlling for differences in factors such as between club training styles, ground surfaces for training, attitudes to footwear and injury management, medical intervention and culture.

A progression of the inter-club study was to apply a similar study design at an intra-club level in which factors such as training style and intensity, ground surfaces, time of day training, and culture are uniform. It was clear from the previous study that a dedicated footwear program has substantial benefits in terms of comfort and injury management.

The aim of the present study was to further examine the role of specific footwear in the football environment. The turf or grass shoe comprises a hybrid football boot design intended to combine the features of a traditional football boot (traction) with the cushioning and technological features of an athletic running shoe. In recent years the turf or training shoe has increased in popularity as the preferred shoe for derivative versions of the rugby codes (Touch Football and Oz Tag), six-a-side football (soccer) which are often played on hard surfaces due to summer environmental conditions, and Aus-kick (an Australian Rules game for juniors). The shoe is often recommended by health professionals as a preferred training or Match-day shoe for junior footballers with growth related injuries, and amateur footballers with joint problems. It is postulated the turf shoe is similar in design to athletic footwear and offers protective features which the football boot does not in regard to torsion stability, cushioning, and foot motion control (Bartold, 1999). The shoe has also increased in popularity among elite footballers in Australia as a training shoe because of the environmental conditions of pre-season training on firm-hard surfaces.

It is currently unknown whether the turf-training shoe provides any benefit over the common football boot in terms of lower extremity comfort and injury related aspects of the style of shoe. The scientific question formulated for the study was “does a turf shoe as an instrument of a tailored footwear program aid the lower extremity comfort of an individual player?”

7.3 METHODS

7.3.1 Study group

A sample of 55 players from one National Rugby League (NRL) organisation was recruited for this clinical trial. The study was conducted over 30 weeks inclusive of a 4 weeks pre-season and 26 weeks of competition. Letters of support for the study conducted was obtained from the football organization involved with the study. Ethics approval was granted from the Human Ethics Committee at Victoria University, Australia.

7.3.2 Study protocols

I. The design of the study was a non-randomised clinical trial. Two groups were formed by natural process using participant preference method (King & Gabbett, 2008). Players who preferred using turf shoes or were ambivalent about the type of shoe used for training were allocated to the training shoe group (intervention). Those who had a preference for football boots were allocated to the football boot group (control).

II. Players in the intervention group were instructed to use turf shoes for all training sessions, with the exception of the last session prior to Match-day which was deemed player choice. The last training session is brief in duration, and often involves a rehearsal of tactical positioning and moves in preparation for Match-day. Players in the control group self selected footwear which was generally football boots for all training sessions. However, to effect player decision making, players from both groups were able to change footwear preferences from a training shoe to a football boot or vice-versa. If at the end of the study period a retrospective analysis revealed a more frequent use of one footwear type over the other, the participant's data were amalgamated into the group which best reflected footwear preference over the period of the study.

III. Both groups had all footwear (football boots, training shoes and athletic footwear) prescribed by a podiatrist skilled in lower extremity biomechanics and footwear. All players where required, had appropriate footwear modification (orthotics, shoe wedging, bespoke). The difference between the groups was the voluntary use of a turf-training shoe or football boots in a training environment. The standardisation of footwear prescription, modifications, and the ability of participants to change footwear preferences ensured all influential biases were controlled and reduced detrimental ethical considerations in terms of providing an unfair advantage to one group.

7.3.3 Data collection

I. Prospective lower extremity comfort was measured weekly using a validated comfort index Chapters 4, 5, and 6 and supported by the publication (Kinchington, et al., 2010). Three comfort zones were established for each player by calculating the sum of six lower extremity anatomical sites and using the median of lower extremity sum scores to set baseline comfort for each individual. Each zone was apportioned an arbitrary colour to reflect level of comfort. Red zone represented poor comfort (median comfort $^{-2\ \text{comfort points}}$). Black zone was associated with median or usual comfort (median $^{\pm 1\ \text{comfort points}}$) and blue zone was a measure of high comfort (median $^{+2\ \text{comfort points}}$).

II. Footwear used for the main training sessions (one to two sessions per week) was recorded under the supervision of the researcher or Club Trainer. Where additional impromptu training sessions were held, footwear data was not recorded because such sessions generally involved field-based skills practice. Only a few players are involved, consisting of kicking or passing ball drills, tackling practice, or a set-move tactical piece. These sessions are often less than 30 minutes and do not involve much running as opposed to intensive main training sessions.

III. Injury was recorded by obtaining statistics gathered by fitness and medical staff. Injury definition for this study was adapted from the World Congress on Sports Injury Prevention Injury Consensus Group (Fuller, et al., 2006). A “time loss” definition was applied where a missed training session or match were recorded. If a medical attention event did not result in full training or Match-day participation, it was not recorded (Hagglund, et al., 2005).

7.3.4 Statistical analysis

Data were analysed using SPSS version 15.0. Alpha P-values less than 0.05 were considered statistically significant. Independent t-tests were used to compute mean values and their standard deviation (SD). Independent t-tests are robust to non-normality (skewness <1 or skewness>1) and were used when there were no influential outliers. To assess the statistical significance of differences in comfort events between the two study groups, mean difference and 95% confidence interval (95% CI) were used as an estimate of effect size. In addition, effect size between group means for comfort and injury data were calculated using Cohen *d*. Where outliers were apparent and data were not normally distributed (Peat & Barton, 2005), a non-parametric Wilcoxon signed ranks test was used to validate the parametric statistic and to confirm that the P value was not over-estimated (Altman & Dore, 1990).

To display results graphically, box plots were used to compare outcomes between groups. In the plots, the dark line represents the median value, the box represents the 25% and 75% percentiles and the whiskers show the range. Column graphs illustrated variations between the groups for comfort and footwear. The prevalence of injury was described as the number of injuries per 1000 player ^{hours}.

7.4 RESULTS

7.4.1 Description of cohort

The physical characteristics of the players are shown in Table 7.1. The retention rate for the study was high (96.3%). Of the 55 players recruited, 53 completed the study. Two drop outs were the result of one leaving the club, and the other player incurred a long term injury invalidating the results. The intervention group consisted of 27 players; the control group 26 players. Data were collected over a 30 week period, representing 180 ^{hours} to 210 ^{hours} of field exposure per player (organised training, individual field sessions and match play). No player completed thirty weeks of data entry. The mean for data collection was 26.6 (SD 2.8) weeks. Reasons for non completion included, player injury, where there was no training participation, player absence from the club at time of data collection, no data collection for one week during the pre-season period because half the squad were away from the club premises making data collection difficult, and on two weeks where data collection was invalidly collected.

Table 7.1 *Physical characteristics of the respective groups.*

	Intervention group (N=32) Mean (SD)	**Control group (N=27)** Mean (SD)
Age [years]	23.3 (3.5)	23.7 (2.7)
Height [cm]	182.9 (5.2)	185.1 (4.8)
Mass [kg]	97.3 (8.6)	98.4 (7.8)

7.4.2 Group footwear characteristics

Footwear data were collected for each week of the study. For the entire sample, 1413 events were collected. The breakdown of footwear was turf shoes (49.6%), boots (43.6%) and other (6.8%). The most common brand of footwear used for training was shoe was Asics (34%), Puma (29%), Nike (20%), followed by adidas (11%), and other (6%).

7.4.3 Control v intervention footwear characteristics

Players who had a preference for one style of footwear (turf or football boot) were allocated into respective groups. At baseline, 15% of the cohort was ambivalent about style of shoe worn prior to the start of the study. As the research question for the study was to investigate the effects of a turf-training shoe, players who had no footwear preference were encouraged to be allocated to the intervention group. In accordance with the study protocol, players were permitted to change footwear preferences. The results indicated all players generally used footwear based upon groupings (Table 7.2).

Table 7.2 *Footwear use in the intervention and control groups*.

	Intervention group N=27	**Control group N=26**
Turf shoe collected events	660	41
%	90.7	6
Mean (SD)	24.4 (2.8)	1.58 (1.7)
95% CI	1.1 (23.4-25.5)	0.6 (0.9-2.2)
Football boot collected events	19	597
%	2.6	87
Mean (SD)	0.7 (0.8)	22.9 (4.3)
95% CI	0.3 (0.39-1.01)	1.7 (21.2-24.6)
Other footwear collected events	49	47
%	6.7	7
Mean (SD)	1.8 (2.9)	1.8 (2.7)
95% C	1.1 (0.7-2.9)	1.0 (0.7-2.9)

The majority of players (77%) alternated footwear at some stage during the study, for a brief period. In the intervention group, 13 players used football boots for training for a total of 19 weeks. Other footwear such as runners was used for a total of 49 weeks by 13 players. In the control group, turf shoes were used by 14 players accounting for 41 training weeks and other styles of footwear by 16 players for 47 weeks.

Alternative footwear was used by players for reasons of training conditions, injury rehabilitation or simply player choice.

7.4.4 Lower extremity comfort

Table 7.3 and Figure 7.1 demonstrate differences in lower extremity comfort between the groups. Overall, the control group had significantly lower comfort scores than the intervention group. The total exposure to rugby league training and game day for the cohort was 7754 hours of field work. It was estimated each player spent approximately 5.5 hours of field work each week for an average of 26.6 weeks which included organised training, impromptu sessions, pre game and match time. The collective number of comfort events was 1410 weeks, mean 26.6 (SD 2.9) over the course of one season. Comfort zones, were divided into poor (red zone) comfort, usual (black zone) comfort and good (blue zone) comfort. The intervention group, had significantly less poor comfort weeks, mean 4.0 (SD 2.8) compared to the control group with mean 9.7 (SD 3.4); $P<0.0001$. Conversely the control group by percentage, had similar good comfort (blue zone) 22% (SD 10.0) to the intervention group 21% (SD 15.4), which was not significant $P=0.73$).

Figures 7.1, 7.2 and 7.3, groups the three comfort zones to indicate the spread of comfort for each zone. For poor (red zone) comfort, the range for the intervention group was 0 to 7 events and for the control group the range was 6 to14 events. The two outliers (9 and 13 poor comfort events in the intervention group) were within the comfort range of the control group players, indicating the narrow spread of poor comfort events. The high (blue zone) plot indicates that while the control group had higher median comfort events, the intervention group had a greater spread of good comfort events.

Table 7.3 *Mean comfort events by group*

	Intervention group N=27 Mean (SD)	Control group N=26 Mean (SD)	Mean difference (95% CI)*	P value[1] (Cohen d)	P value[2] (Cohen d)
Collected events	27.0 (1.8)	26.8 (2.0)	0.2 (-0.8, 1.2)	0.7	
Poor (red zone) comfort events	4.0 (2.8)	9.7 (3.4)	-5.6 (-7.4, -3.9)	<0.0001 (1.79)	
%	15 (10)	37 (10)	-22.4 (-28.0, -16.9)	<0.0001	
Usual (black zone) comfort events	17.4 (4.5)	11.0 (3.7)	6.3 (4.1, 8.6)	<0.0001 (1.2)	
%	64 (16)	41 (13)	23.5 (15.5, 31.6)	<0.0001	
High (blue zone) comfort events	5.6 (4.1)	5.9 (2.7)	-0.3 (-2.2, 1.6)	-	0.8 (0.08)
%	21 (15)	22 (10)	-1.1 (-8.3, 6.1)	-	0.8

** a positive value favours the intervention group, a negative value favours the control group*
1 Parametric P value using independent samples t-test
2 Non-parametric P value using Wilcoxon signed ranks test

Figure 7.1 *Poor (red zone) comfort events*

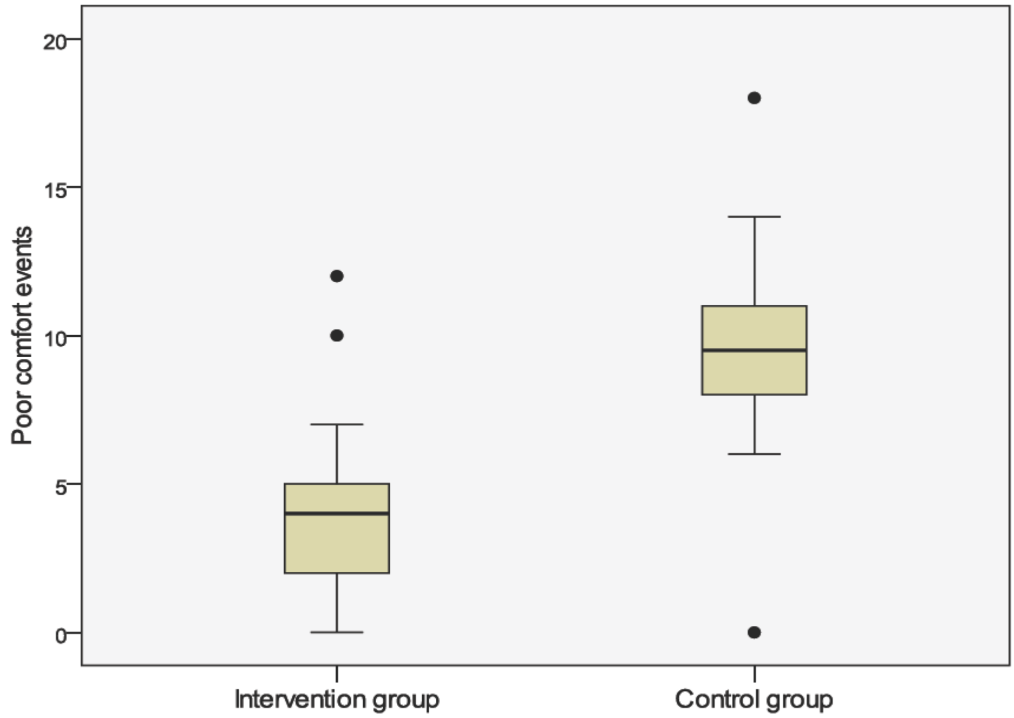


Figure 7.2 *Usual (black zone) comfort events*

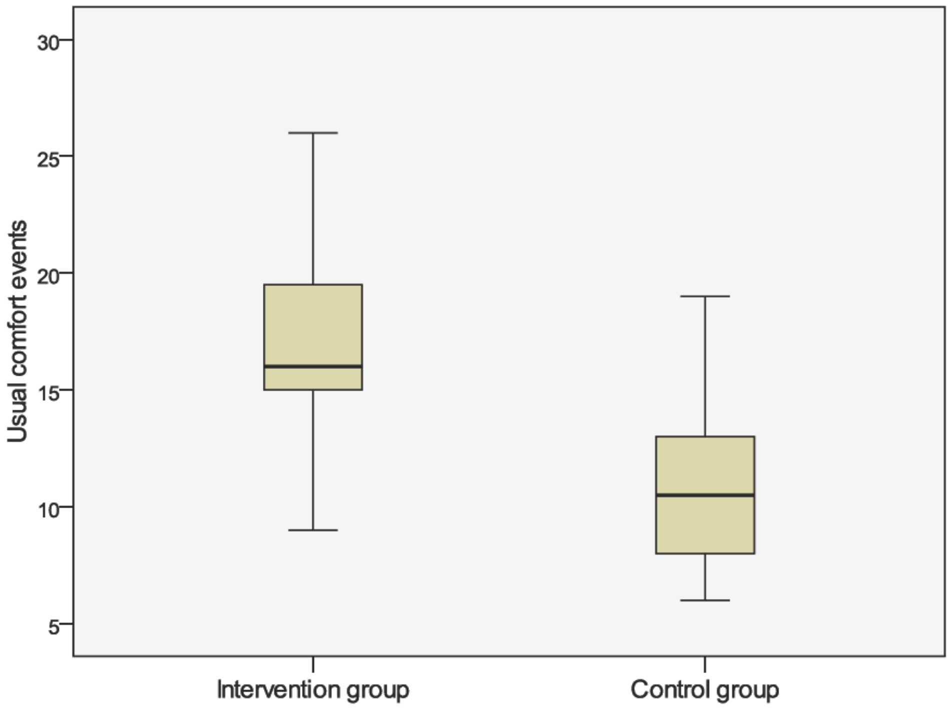
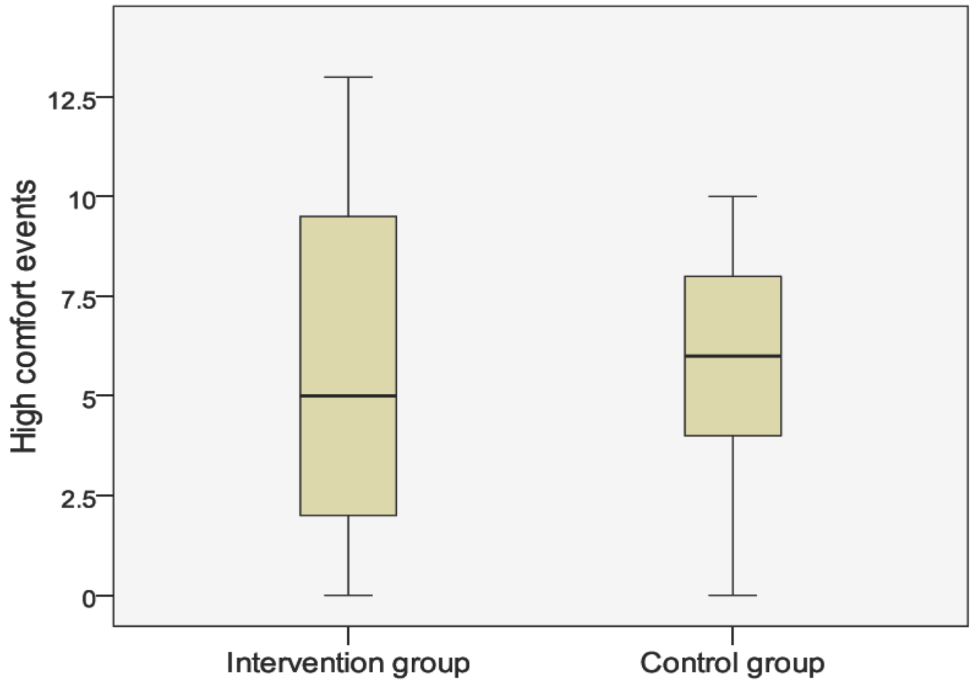


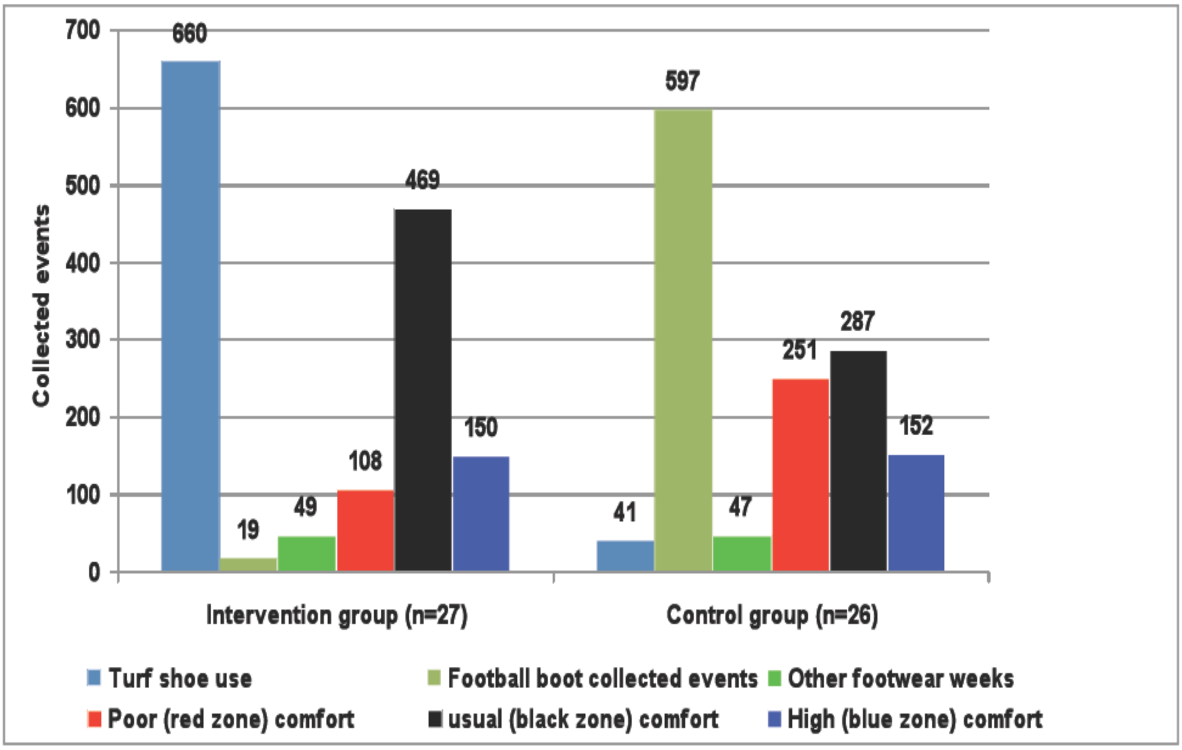
Figure 7.3 *High (blue zone) comfort events*



7.4.5 Lower extremity comfort and footwear

Figure 7.4 shows differences between the groups for lower extremity comfort and type of footwear used over the period of the study. The graph shows that a designated training shoe (turf shoe) which was prescribed for all players had a positive impact on lower extremity comfort scores, with more usual comfort weeks during the test period and less poor comfort events reported by intervention group who wore turf shoes on 91% of occasions. In the control group where football boots were used 87% of time, poor lower extremity comfort events were recorded more than twice as often. Both groups used other styles of footwear about the same proportion of the time, generally for running sessions and rehabilitation training.

Figure 7. 4 *Lower extremity comfort association with footwear for control and intervention group*



A breakdown of footwear comfort by player indicated that not all players responded as expected to the effects of footwear over the period of the study (Table 7.4). For example in the control group, one player did not record any poor comfort events. Conversely, three players registered poor comfort 51-60% of the time with football boots. In the intervention group, one player recorded poor comfort on 43% of occasions.

As the majority of the control group (79%) recorded poor comfort between 20-50% of time and 78% of the intervention group recorded poor comfort less than 21% of the time, the results demonstrated the sensitivity of footwear style for the majority of players as opposed to group responses. Over the study period 24 players in the intervention group recorded poor comfort between 0-25% of the time. The highest number of poor comfort events recorded was 12 events for one player in the intervention group who experienced 8 non-contact *time loss events*.

Table 7.4 *Poor comfort by percentage rank for both groups*

Poor comfort event (red zone comfort)	**Control group comfort responses N= 26**	**Intervention group comfort responses N=27**
0-10%	1	11
11-20%	0	10
21-30%	7	4
31-40%	10	1
41-50%	5	1
51-60%	3	0

7.4.6 Injury events for intervention and control groups

Of the 53 players who participated, 48 players (92.3%) sustained an injury resulting in at least one missed session. Over the period of the study, 149 injury occasions accounted for missed training (359), mean 6.8 (SD 4.7) and missed games (99), mean 1.9 (SD 3.3). Injury per 1000 player ^{hours} for the groups was 17.6 with a rate for the control group of 24.81/1000 ^{hours} and for the intervention group of 12.91/1000^{hours}. Overall, the control group had greater prevalence of injury, which resulted in a significantly more *time loss events* (P<0.0001; Cohen d=1.39) for both training and Match-day events.

Table 7.5 *Injury data for Intervention and control groups expressed as injury prevalence and time loss events*

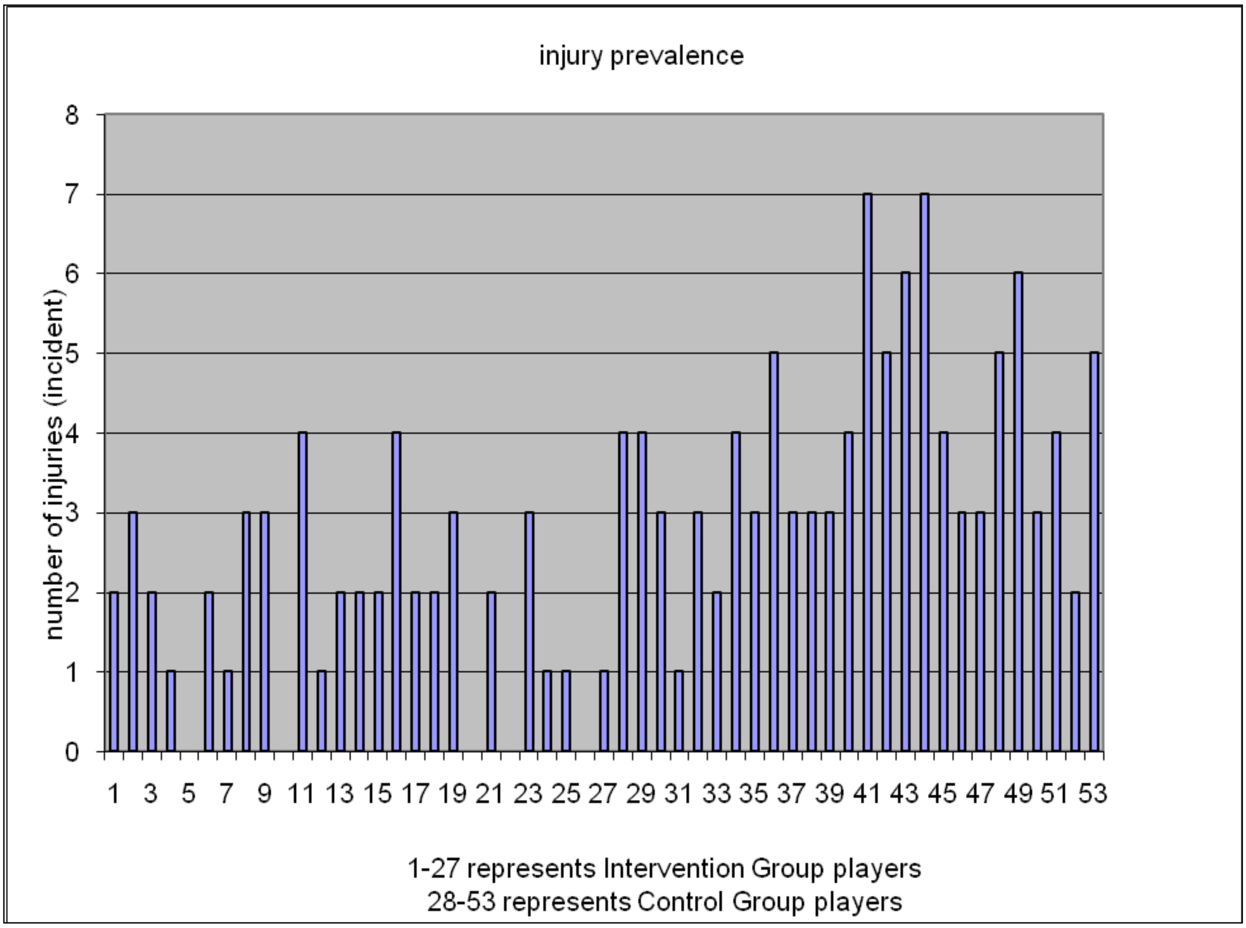
	Intervention group N=27 Mean (SD)	Control group N=26 Mean (SD)	Mean difference (95% CI)	P value[1] (Cohen d)
Injury prevalence	1.7 (1.2)	3.9 (1.5)	2.2 (-2.9, -1.4)	<0.0001
Injury prevalence %	6 (5)	14 (6)	7.5 (-10.5, -4.5)	<0.0001
Missed sessions total	4.5 (4.9)	13.0 (6.9)	8.5 (-11.8, -5.2)	<0.0001 (1.39)
Missed training	3.9 (4.1)	9.8 (3.2)	5.9 (-7.9, -3.9)	<0.0001 (1.59)
Missed matches	0.6 (1.4)	2.5 (2.6)	1.9 (-3.0, -0.7)	0.002 (0.83)

1 Parametric P value using independent samples t-test

7.4.7 Injury prevalence for individual players

Figure 7.5 indicates injury prevalence per player. The data establishes a trend for the injury to be higher in participants 28-53. This end of the graph represents control group data. Four players in the intervention group did not record any *time loss events* for lower extremity injury, but all players in the control group sustained at least one *time loss event*. However, there were insufficient events to conclude that the use of the turf shoe as a training shoe was the reason for no *time loss events*. The maximum number of injury events for the intervention group was 4 events compared with 7 events for the control group. Significant differences (P<0.0001) were found for time loss per injury between the control group (mean 13.0, SD 6.9) that was more than twice the time loss of the intervention group (mean 4.5, SD 4.9).

Figure 7.5 *Injury prevalence for each player indicating dichotomy between intervention and control groups.*



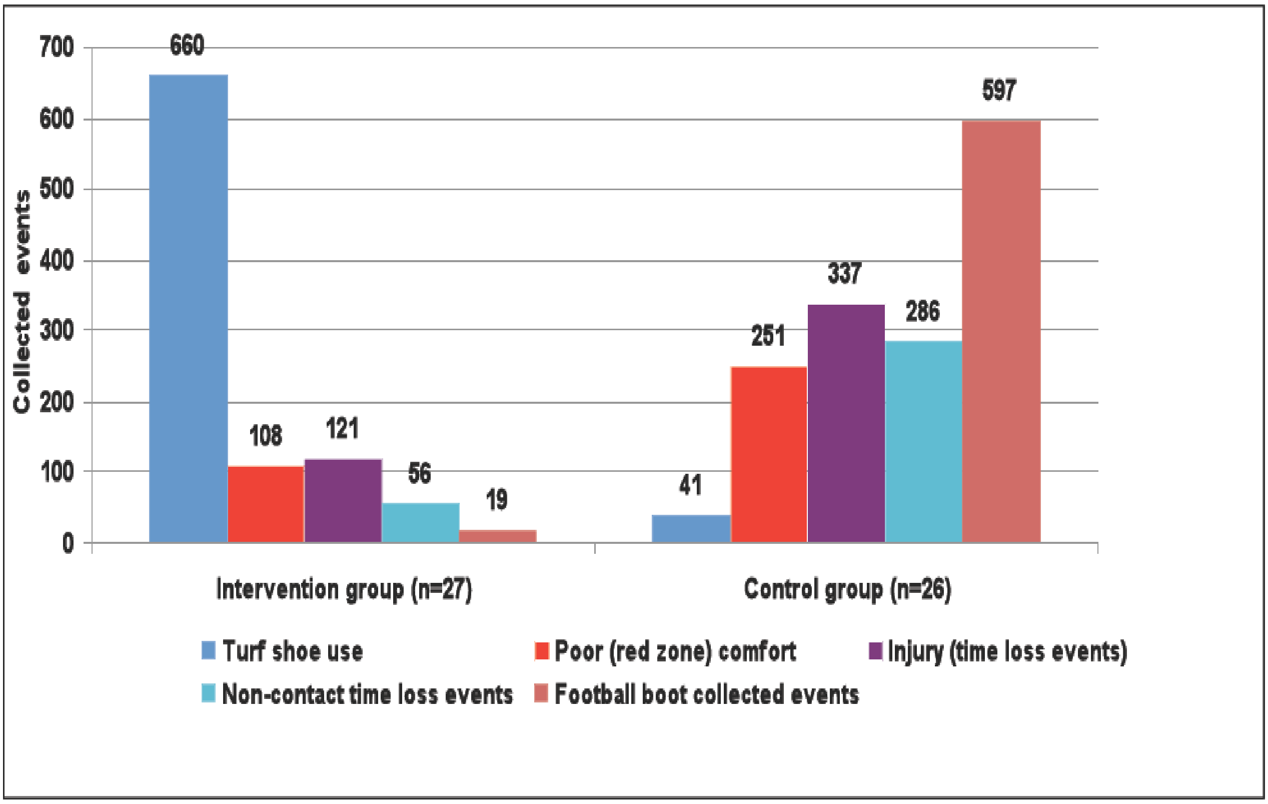
7.4.8 Non-contact time loss events for control and intervention groups

To scrutinize the injury data further, groups were compared post-hoc for time loss by non-contact injury. The results indicated agreement between non-contact injury events and time loss. For the groups, overall non-contact injuries represented 74.6% of *time loss events*. The intervention group accounted for 36%, mean 2.1 (SD 3.1) events per week compared with the control group 84%, mean 11.0 (SD 6.6), P<0.01; Cohen d= 1.70. The assessment of the data by non-contact events provided insight to injury, as non-contact injuries are considered modifiable to some extent by the use of preventative and rehabilitation programs.

7.4.9 Relationship between footwear type, comfort and injury

Figure 7.6 shows the association between the turf shoe, the affect on lower extremity comfort, and the outcome for non-contact *time loss events* and training-Match-day *time loss events*. The players in the intervention group used turf shoes for 660 accumulated weeks. During the weeks that the turf shoes were recorded as worn, poor lower extremity comfort occurred on 108 occasions (17%). Overall, poor lower extremity comfort was 15% when all styles of footwear were tested (Table 7.2). As a consequence of poor comfort, 121 *time loss events* occurred of which less than half (46%) were due to non-contact injury events. The results for the control group indicate that when football boots were used as the primary shoe for training over the 30 week period of the study, poor lower extremity comfort occurred on 251 occasions (42%). The number of non-contact *time loss events* was 286 from a total of 337 *time loss event* weeks which was a high 85%.

Figure 7.6 *The effect of footwear type on comfort and injury for control and intervention groups.*



7.5 DISCUSSION

Lower extremity foot-ankle injury reduction is an important criterion in professional football for multiple reasons ranging from performance-based criteria (player welfare, footballer form, team cohesion due to lack of injuries, winning games) to financial considerations (player payments, medical rehabilitation costs, club sponsorship). The results indicate the dichotomy between lower extremity comfort and *time loss events* between the groups. Over the 30 week study period, the intervention group, which utilized designated training footwear, scored higher lower extremity comfort and experienced fewer *time loss events*. These results validate theoretical propositions that footwear can be a used as a tool to improve comfort (Mündermann, et al., 2003a) and prevent injury (Hennig, 2008) as well as having a detrimental effect upon the musculoskeletal health of an individual (Bishop, Fiolkowski, Conrad, Brunt, & Horodyski, 2006; Walden, Hägglund, & Ekstrand, 2007).

The nature of this study was a non-randomised clinical trial involving players from the same football organisation. In the design of the study, the protocols employed were mindful of ethical considerations such as giving a perceived advantage to one group over another. Such considerations are particularly relevant to control and intervention group comparisons that utilizes a one team model. Potential detrimental outcomes is an effect upon the health of players and the broader consequences of injury which may threaten playing careers, jeopardizing future player earnings and compromise team results. The study attempted to minimize potential effects by standardizing the footwear protocols between the control and intervention groups, ensuring all players had access to the same standard of medical techniques and care, and enabling players to switch footwear if desired. The process of natural select allocation into either the intervention group who utilized a turf-training shoe, or the control group who used a conventional football boot as the primary training shoe, was deemed by the researcher the most ethical process of implementing an intervention study. Despite acknowledged design limitations, the protocol of the study enabled players to change footwear preferences as desired. It would be impractical to expect professional footballers to be restricted in self selection processes as occasions would arise where alternative footwear is necessary.

The study was conducted over 30 weeks of football, including 4 weeks pre-season and 26 rounds of NRL competition. The data excluded 3.4 weeks of results for which too few respondents provided meaningful data. This was due to impromptu meetings which often occur at football organizations and a training camp away from the club facilities which interrupted data collection. Such interruption to field studies utilizing professional athletes are a common hindrance to research and is a limitation which like studies need to be mindful of. This study was not effected as multiple weeks of data was collected from a large group of individuals.

Prospective lower extremity comfort was recorded for all players for the period of the study using a Lower Limb Comfort Index (LLCI); Chapters 4, 5, and 6 and supported by publications (page VIII). The sensitivity of the LLCI is illustrated by the differences observed in comfort scores associated with style of shoe used (Figure 7.4). The results of this study are in agreement with other published studies, where clinical benefits of footwear interventions provide a means of affecting aspects of health and well-being (Kinchington, 2003; Mündermann, et al., 2003a). The studies that comprise this thesis are the first to address footwear effects in professional football across all codes. It is anticipated the data will contribute to footwear selection guidelines and provide a strategy to guard against injury.

The breakdown of brands for training shoes is indicative of available models in the market place. All footwear manufacturers offer turf-training shoes, however, Asics and Puma dominated the market place during the period this study was conducted. While Asics and Puma were the most popular brands utilized (63%) for training, a diverse range brands and models were used on Match-day. The effect of turf shoes as a training dedicated shoe had significant benefits upon lower extremity comfort ($P<0.0001$). While the comfort result was hypothesized due the cushioning and protective features of the turf-training shoe, the injury outcome was an unexpected result. It is speculated that the cushioning effect of the shoe has protective qualities for the entire musculoskeletal lower extremity unit. Midsole cushioning within athletic footwear is important for, the attenuation of gait related impact forces (Shorten & Mientjes, 2003), guiding foot motion (Stacoff, et al., 2001) contributing to joint energy return and energy loss (Stefanyshyn & Nigg, 2000), and beneficial to lower extremity muscle activity (Wakeling, et al., 2002). This in turn reduces impact forces and loading which correlate with musculoskeletal injury, including stress fractures (Iwamoto & Takeda, 2003), knee pain (Duffey, Martin, Cannon, Craven, & Messier, 2000) degenerative joint disease (Collins & Whittle, 1989) and tendon problems (Richards, Ajemian, Wiley, Brunet, & Zernicke, 2002).

The alternative argument is that the football boot is not suited to high volume running and training. The trend for football boots is to be lighter. Therefore, more flexible and less restrictive footwear will not perform the essential primary purpose; of protecting the foot from the environment. A growing body of evidence supports the contention that ground conditions are implicated in lower extremity injury (Gabbett, et al., 2007; Orchard, 2002; Orchard, Seward, McGivern, & Hood, 1999; Villwock, et al., 2009) thus interaction between shoe and ground needs further investigation (Milburn & Barry, 1998). Future clinical guidelines for footwear selection may require consideration to be given to factors including lower extremity comfort, injury status, type of training being performed (physical v skills) and ground conditions.

This study which is the first to investigate the role of two different styles of training footwear within the same professional football organization highlighted the protective role a designated turf-training shoe can have upon player well-being. Education programs for footballers and staff may be of benefit to highlight the importance of footwear outcomes. Future projects may include the investigation of footwear habits of professional athletes, and assess footwear awareness among health professionals who treat lower extremity musculoskeletal injury. A possible intervention to emerge from this study is for codes of football which are played on firm-hard surfaces to encourage the use of turf-training footwear.

Injury prevention and management of lower extremity musculoskeletal conditions can be modified through targeted programs (Twomey, Finch, Roediger, & Lloyd, 2009). The collection of injury data is regularly catalogued by football organisations in an effort to benchmark against other football teams and to make improvements to injury management. The results of this study indicate the LLCI as a valid clinical tool to measure the effects of footwear on lower extremity comfort and injury outcomes. All injuries (missed training and matches) were recorded as *time loss events* and were cross referenced between medical and conditioning staff to ensure accuracy. The intervention group missed less training and matches than the control group who used football boots as the primary training shoes. However, further insight as to injury severity was capable by assessing whether the injury was due to contact or non-contact as this type of injury is considered to be modifiable. When the style of footwear was assessed for the respective groups for non-contact injuries (Figure 7.6) there was a close relationship between football boots, poor comfort and non-contact *time loss events*. The control group, non-contact *time loss events,* was mean 11.0 (SD 6.6).The intervention group which had a low number of poor comfort events also had a low number of non-contact *time loss events*. A conclusion drawn is that non-contact *time loss events* were affected by the non-use of turf-training footwear. Thus, a proposed intervention to emerge from the study is that the use of turf shoes as a dedicated training shoe may aid a reduction in lower extremity injury.

Despite these results, intervention footwear programs need to be mindful that not all players will respond to footwear as expected. Mechanisms of how footwear interacts with the musculoskeletal system and protects the body from injury and poor comfort remain unknown. The protective aspects of footwear are complex and multifactorial and quantification remains a difficult challenge for researchers (Nigg, 2001). In the study presented, while the majority of players responded favourably to turf shoes in terms of lower extremity comfort, one player within the intervention group who used turf shoes for all training sessions registered poor lower extremity comfort on 12 occasions (41-50%) resulting in 8 *time loss events*. A possible reason for the result was the footballer was a first year, rookie footballer, and was considered musculoskeletal immature. The *time loss events* were due to tibial stress fractures. There was a measurable weakness in calf muscle strength which is associated with shin overload. The combination of rookie player and calf muscle strength has both been identified as risk factors for football (Iwamoto & Takeda, 2003; Johnson, Doherty, & Freemont, 2009). This result highlights the need for caution when implementing broad footwear policies to large groups of individuals. Footwear prescription needs to take into account factors such as ground conditions, weather and environment, well-being of an individual, body weight and personal preferences. These variables were outside the scope of this study and may be the investigation of future studies. Therefore, caution should be taken when formulating footwear policies which are implemented on a mass scale. Players will respond differently to the stimulus of footwear and so individual prescription considerations are required.

The need for individual comfort monitoring rather than group results is highlighted by the case of a player in the study who did not record any poor comfort scores, but did register eight *time loss events*. All comfort rankings (poor, usual and high comfort zones) need to be investigated for each individual to obtain a full brief on aspects of lower extremity well-being. Poor lower extremity comfort as designated by poor comfort measures were not associated with *time loss events*. In this example, time loss occurred despite comfort readings registered as black zone (usual) comfort. This result indicates caution is needed when relying upon the LLCI as an instrument to predict injury. The failure of the poor comfort not to capture the *time loss event* in all circumstances was consistent with previous modelling of the LLCI (Chapter 5) and the supporting publication (Kinchington, et al., 2010).

The intra-club study of footwear and comfort was conducted over one NRL season. Many studies of football are conducted over one season (Orchard & Seward, 2008; Walden, et al., 2007). Others studies conducted over several football seasons, show no significant differences for injury incidence, concluding one full season coverage is an adequate representation of injury (Hagglund, 2007). Further, the rate of injury incidence for this study is within the range of other rugby league (Gabbett & Godbolt, 2010; King, et al., 2005) and football (soccer) studies (Hagglund, et al., 2005), when adjustments are made for the fact this study only included lower extremity injury and not whole body injury. Factors in the study which were not controlled for include bias due to talent, intensity differences between 1st & reserve grade, years of professional football experience, musculoskeletal maturity which may have an effect upon pain perception and injury coping strategies.

An inherent difficulty of injury research is the many confounders which are intertwined as components of injury. No one isolated factor dominates the lower extremity injury paradigm and no one intervention is a panacea for management of injury. Rather, injury predictors and interventions are multi-factorial, complicated, and require constant intervention and revision. The results show that the use of the LLCI to measure lower extremity comfort is one such technique to gather injury component data. A perceived advantage of the LLCI is the ability to prospectively accumulate data for a large cohort of footballers. This enables comparisons to be made on lower extremity health, comfort and injury when interventions are applied.

7.6 CONCLUSIONS

Lower extremity comfort can be affected by footwear which has important consequences for injury management and player welfare. The study shows an important association between comfort, style of footwear and injury outcomes in an intra-club testing environment and extends the knowledge base of other research which has examined the relationships described in this study. This research provided evidence that the football boot when worn for extended periods contributes to poor lower extremity comfort and that a dedicated training shoe may offer protection to players over the course of a football season. These results offer a platform to develop clinical footwear guidelines and educative programs to footballers, coaching staff and medical personnel.

CHAPTER EIGHT

RELATION BETWEEN LOWER LIMB COMFORT AND PERFORMANCE IN ELITE FOOTBALLERS

This chapter is supported by the publication:

*Kinchington, M., Ball, K., Naughton, G. (*http://dx.doi.org/10.1016/j.ptsp.2011.02.001; in press, 2011). *Relation between lower limb comfort and performance in elite footballers. Physical Therapy in Sport.*

8.1 ABSTRACT

Background: Successes of the professional athlete as individuals and team, across codes of football are contingent upon performance measures. A speculative theory is performance has a multi-factorial aetiology, including a pragmatic link between comfort and performance. However, there is limited corroborative evidence to support the concept.

Objectives: Examine associations between comfort and performance in professional football. The study hypothesis was poor lower limb comfort is negatively correlated with good Match-day rated performance.

Methods: Prospective measures of lower extremity comfort and coach rating performance criterion were applied to 79 professional footballers from two codes (Australian Rules and Rugby union) for one complete football season. Comfort and performance associations were described using Pearson's correlation coefficient (r) or the R square value from the regression estimate. Aspects of validity and responsiveness to change tested the hypothesis that lower limb comfort, affects rated performance. The validated LLCI (Chapters 3, 4, 5) was used to test comfort.

Results: Poor lower limb comfort and good Match-day ratings were not well correlated (R^2 =0.25, P=<0.001) and usual-high comfort was correlated with usual-good performance (R^2 =0.69, P=<0.001).

Conclusions: This study represents the first to assess the relationship between lower extremity comfort and rated Match-day performances in professional football. Lower limb comfort may be a sensitive measure of rated performance in football. The application of this study is the use of lower limb comfort measures, via the LLCI, to assist in decision making on the potential playing status of an individual.

8.2 INTRODUCTION

Performance is an area of elite sport in which all athletes and coaches strive to improve. Because there is no one accepted measure of sporting performance (Young & Pryor, 2007), various measures of performance are used to assess individuals. These range from quantitative game statistics using parameters such as running distance covered, speed and intensity (Coutts & Duffield, 2010), to assessment of game skills (Szczepanski, 2008) as well as physiological and anthropometric testing (Reilly, Bangsbo, & Franks, 2000).

There are also psychological, technical and tactical factors, the measures of which are largely subjective as one person's opinion of skill execution will differ from another. Despite acknowledged limitations, subjective judgements of performance are sufficiently credible and trainable to be accepted as valid scoring systems in Olympic and World Championship events such as diving, gymnastics and boxing. In regard to football performance, opinions canvassed among AFL coaches in a state league competition, showed team performance was associated with various skill executions (Twomey, et al., 2009) and as such, also showed subjective opinion has an element of credibility.

Injury has socioeconomic and financial consequences (Dvorak, et al., 2000) and also affects sporting performance. Pragmatically a link between injury and performance is clear. However, there is limited corroborative evidence to support this link. A speculative theory is performance, like injury, has a multi-factorial aetiology including factors such as varying states of psychological and physical well being, environmental and equipment factors. The role of neurophysiology and neuromuscular responses and pain inhibition as a determinant of performance is not well understood. However, comfort may play a role in determining performance (Luo, et al., 2009) among the football codes (Hagglund, 2007; Orchard & Seward, 2008).

The lower extremities have been identified as a dominant region of the human body vulnerable to injury in the football codes (Hagglund, 2007; Orchard & Seward, 2008), running (Van Middelkoop, Kolkman, Van Ochten, Bierma-Zeinstra, & Koes, 2008) and multiple other sports (Twomey, et al., 2009). Therefore an extension of the injury paradigm in sport is an investigation of whether lower extremity comfort affects performance. Previous studies of footwear discomfort, propose an alteration of lower extremity muscle loading during running may cause muscular fatigue and be detrimental to subsequent performance (Nurse, et al., 2005; Wakeling, et al., 2002). The mechanism by which this occurs involves the capacity of the body’s sensory system to respond to variations of footwear stimuli or lower extremity discomfort which alters impact forces (Miller & Hamill, 2009; Zadpoor & Nikooyan, 2010). Strong evidence supports the theory of comfortable footwear providing a protective function to the lower extremity by load attenuation and cushioning that collectively creates a state of comfort (Mundermann, et al., 2001; Nigg, et al., 1999; Witana, et al., 2009; Yung-Hui & Wei-Hsien, 2005). Performance can also be affected by muscle soreness (Reilly, Drust, & Clarke, 2008). Mechanical damage to muscle leads to discomfort and affects athletic performance altering strength, range of motion, proprioception and biomechanics of gait (Byrne, Twist, & Eston, 2004). Altered muscle sequencing results in disruption to usual movement patterns and compensatory musculoskeletal mechanisms may occur, compromising performance and increasing risk of injury (Cheung, Hume, & Maxwell, 2003).

Techniques used to assess the health of athletes which may affect performance of athletes include systems to track wellness (Von Guenthner & Hammermeister, 2007), monitoring of physical loads (Hartwig, Naughton, & Searl, 2008) regular assessment of players physical profiles (Rösch, et al., 2000) and health related screening programs (Holzer & Brukner, 2004).

Pertinent to the lower extremity, the role of neuromuscular and neurophysiologic effects of increased loads, musculoskeletal disorders, delayed onset muscle soreness, and factors that detrimentally impair player wellness, may affect the ability to train and so compromise football conditioning (Gabbett, 2006a) and also impair performance skills (Verrall, Kalairajah, Slavotinek, & Spriggins, 2006). The use of a LLCI in elite football was shown to be reliable and valid (Chapters 4, 5, 6 and 7). The theoretical basis for this proposition is the complex interaction between the cerebral cortex and neural stimuli which differentiates between a state of discomfort (pain) and comfort (Karoly, et al., 1987) and has been documented in Chapter 3. The response of the musculoskeletal system to loading involves the capacity of the body' to respond to variations of impact forces associated with activity (Mündermann, et al., 2003a; Zadpoor & Nikooyan, 2010). When tolerance levels are breached, pain and discomfort occurs, which alters rate of lower extremity muscle loading, that has been linked to musculoskeletal disorders, muscular fatigue and performance effects (Wakeling, et al., 2002). By measuring limb comfort over time, quantitative data on the physical preparedness of a player can be obtained. An extension to the potential use of comfort to determine injury (Chapter 5) is the proposition that comfort may also affect performance.

In the environs of elite sport, athletes are rarely free from musculoskeletal discomfort and often will contend with multiple areas of discomfort at the one time. Thus some capacity of athletes to perform well with discomfort and injury may be a necessary condition for elite sports participation.

A system that evaluates comfort may provide a mechanism to measure the overall state of lower extremity well being, and be compared to performance measures. The aim of this study was to examine the association between lower extremity comfort and rated performance, the foci being the evaluation of rated performance of professional footballers using subjective rating criterion of experienced team coaches on individual player's game response.

8.3 METHODS

8.3.1 Data collection

The cohort for this study comprised 79 athletes from two football codes played in Australia (Rugby Union, and Australian Rules). Aspects of validity and responsiveness to change were used to test the hypothesis that lower extremity comfort affects performance. Lower extremity comfort data were collected using a previously validated index (Chapters 4 and 5). The data were collected following a final training session for each week of in-season competition which represented 24-30 $^{\text{hours}}$ before match participation (Match-day). Letters of support for the study were obtained from the respective organizations. Ethics approval was granted from the Human Ethics Committee at Victoria University, Australia.

8.3.1.1 Lower extremity comfort

Lower extremity comfort was prospectively collected for the period of the study using the protocol previously described in the thesis. For home venue games, the data were collected in an environment familiar with the players. For away venues, the data were collected at the hotel at which the team was residing. The researchers supervised the entry of data by the players at all home ground matches, and when data collection occurred at away matches, the medical and conditioning staff of the respective football organisations assisted with data collection. Throughout the study, the lower extremity comfort data remained confidential and were not provided to the coaching staff and were not used as selection criteria. The players were aware the comfort data they provided would not negatively prejudice match participation.

A sum score for lower extremity comfort was calculated for each player and represented an aggregation of six anatomical areas (foot, ankle, calf-Achilles, shin, knee, football boot) totalling 36 $^{\text{comfort points}}$. Each anatomical area was scored between 0 $^{\text{comfort points}}$ and 6 $^{\text{comfort points}}$. A score of 0 $^{\text{comfort points}}$ indicated extreme discomfort, being unable to run or jump, and 6 $^{\text{comfort points}}$ was extremely comfortable. Comfort zones for each player were determined post hoc using median scores from the collected data. Post hoc was defined as end of season (16 rounds of competition in the Rugby Union Super 14 competition and 26 collected events in the Australian Rules national competition). The analysis of post-hoc comfort data was deliberate to allow for significant changes to comfort levels which may have occurred during the monitoring period, because lower extremity zone comfort may re-set due to football relevant factors including surgery, football conditioning, and changing musculoskeletal maturity.

Three comfort zones were established. Each zone was apportioned an arbitrary colour to reflect level of comfort. The calculations used for the three comfort zones were: Poor (red zone) comfort $^{\text{median -2 comfort points}}$; Usual (black zone) comfort $^{\text{median ±1 comfort}}$; High (blue zone) comfort $^{\text{median +2 comfort points}}$. The apportioning of the upper and lower zones was established by trials using other scores above and below the median. The use of ±1 $^{\text{comfort points}}$ above or below the median was too narrow to delineate high and poor zone because it did not allow for some fluctuation in factors. Scores ±3 $^{\text{comfort points}}$ created range too wide to establish meaningful outcomes. Comfort and performance which are not empirical measures by their nature will vary. Therefore, a median range is appropriate.

8.3.1.2 Rated performance data collection

Lower extremity comfort was compared to rated Match-day performance to assess the extent to which lower extremity comfort was related to performance. For the purpose of this study, performance was defined as the collective subjective rating of experienced coaches on each player's game response. The measurement of performance for each code of football was limited to subjective evaluation by a maximum of four members of the coaching staff for the respective code of football. The ratings of performance were inclusive of physical and tactical responses of the players. While notional data using parameters such as workloads, running distances, ball possessions, tackles and number of kicks are relevant criteria to quantify performance, non-quantifiable parameters such as the influence of ground environment, game tactics, and importantly specific coaching instructions to a player are considered integral to individual rated performance. It is these subjective, non quantifiable areas of performance; i.e. coach evaluation of known tasks for each player, based on game plans, that have greater relevance to coaching staff to rate the performance of players.

The exact rating criteria will differ between clubs and guidelines which suit one club may not be considered important to another club or code of football. Therefore knowledge of the criteria used to rate player performance is not relevant to the study. The researchers were blinded to the methods used to evaluate performance and did not access the data until the end of the collection period. Performance zones were determined post hoc using median scores from the collected data. Using the same format to rank lower extremity comfort, Match-day rated performance were classified into zones: good (blue performance rating), usual (black performance rating), and poor (red performance rating).

8.3.2 Statistical methods

Data were analysed using SPSS v 15.0 for Windows (2006). For all analyses, $P < 0.05$ were considered statistically significant. Continuously distributed variables were summarized as means, standard deviations (SD) and 95% confidence intervals (95% CI) where appropriate. To display results graphically, box plots and column graphs were used to show comfort zones and Match-day ratings. In the box plots, the dark line represents the median value, the box represents the 25% to 75% percentiles and the whiskers show the range. Scatter plots were used to display associations between two continuous variables. The size of the association between continuous variables was described using Pearson's correlation coefficient (r) or the R square value from the regression estimate.

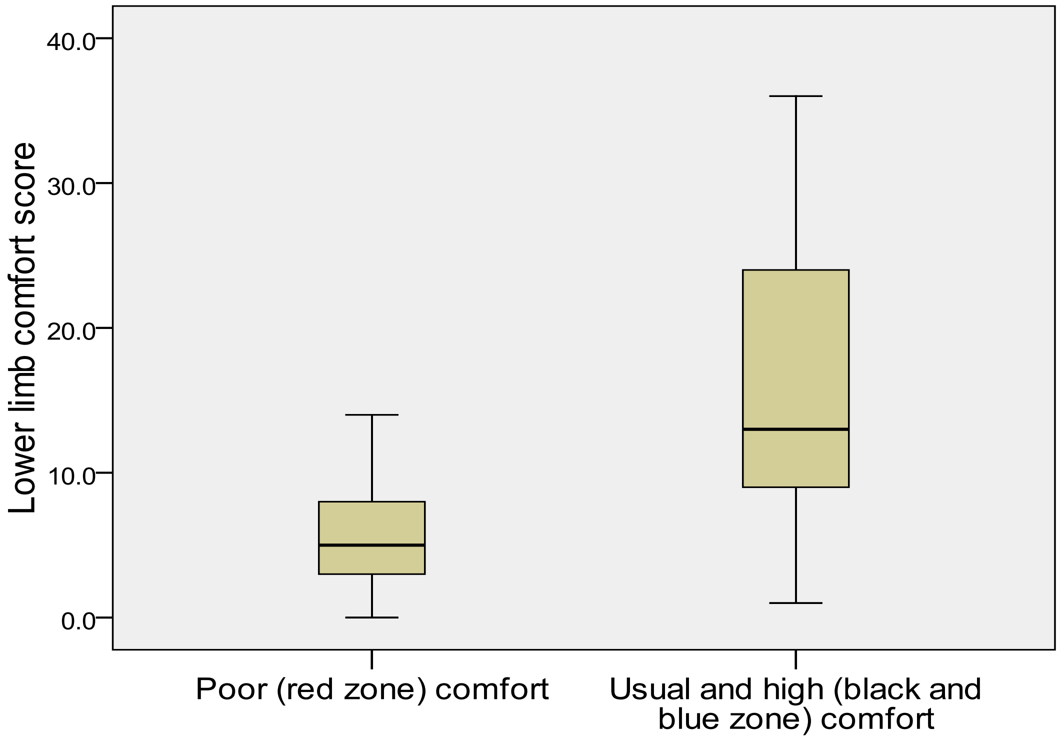
8.4 RESULTS

Descriptive data for participants were age: mean 24.1 years (SD 3.6), mass 95.2 kgs (SD 8.3); height 184.4 cms (SD 5.1) cm. No significant differences were observed in age and anthropometric measurements between the two different codes of football recruited for the present study. A total of 1724 player weeks of data were collected, mean 21.9 (SD 11.5) weeks per player. Of the cohort recruited, data for 79 players was utilized. Data for 13 players was excluded due to insufficient numbers of comfort events recorded, not enough match rating exposure events and player data which were more than 3 SD from the group outliers were excluded because they would bias results in favour of the research hypothesis.

8.4.1 Match-day comfort

Match-day ratings were compared to Match-day comfort events at the end of the data collection period. Figure 8.1 shows Match-day comfort for 79 participants for 1724 data collection events. Poor comfort (red zone) represented 25% of lower extremity comfort scores, and Usual and High comfort (black and blue zones) represented 75% of comfort events. Usual and high comforts were combined, as the two comfort zones were not considered to be detrimental to performance. The median number of usual and high comfort events as represented by black-blue zones was 13 per player. This was an expected result as comfort changes with time and for many weeks players will participate with some level of discomfort. The median number of poor comfort events was five (5) per player.

Figure 8.1 *Comfort events for 79 players from two codes of professional football (Australian Rules and Rugby Union).*



8.4.2 Relation between comfort and performance

Figure 8.2 compared match ratings with poor (red) comfort scores. When poor comfort scores were recorded (426 events) there was a high proportion of poor match ratings (60.3%) and a low number of high (blue) match ratings (5%). The results show a clinical trend between poor (red) zone comfort scores and poor (red) match performance ratings. The conclusion was when players' lower extremity comfort is poor; performance was compromised when adopting coach ratings as a measure of performance. However, a direct association between the comfort and match rating scores did not occur on all occasions, as usual (black) match ratings (35%) and high (blue) match ratings (5%) still occurred with poor comfort scores. Nevertheless, the result for good performance indicates it was unlikely an individual performance would be rated good or usual when lower extremity comfort was poor.

Figure 8.2 *The proportion of performance (match ratings) to poor comfort (red zone) events (y axis).*

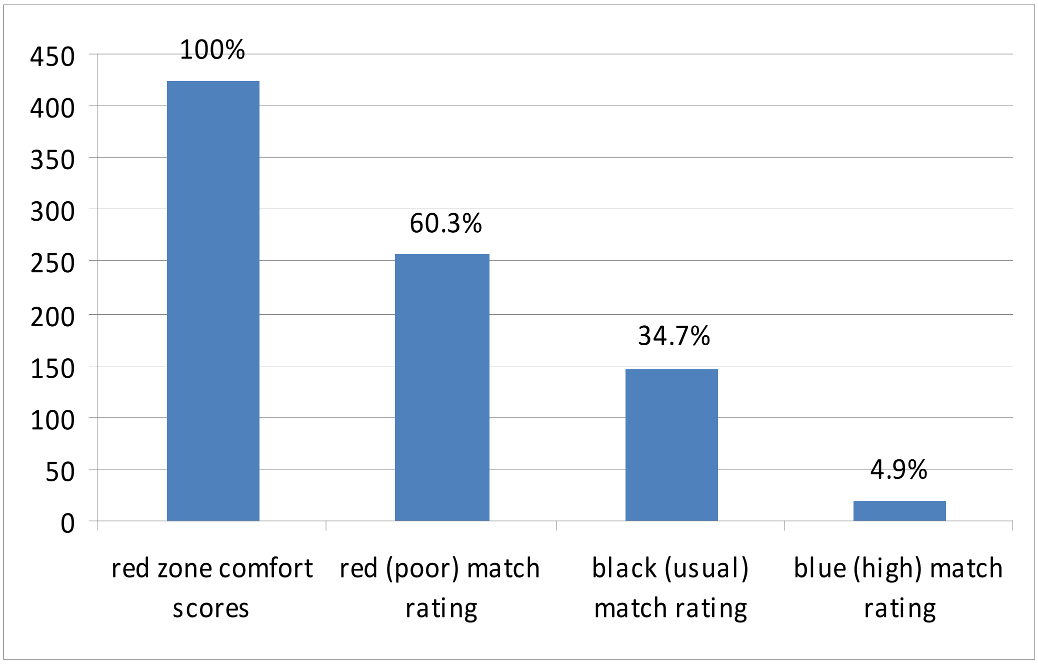


Figure 8.3 *The proportion of performance (match ratings) to comfort (black-blue comfort events; y axis).*

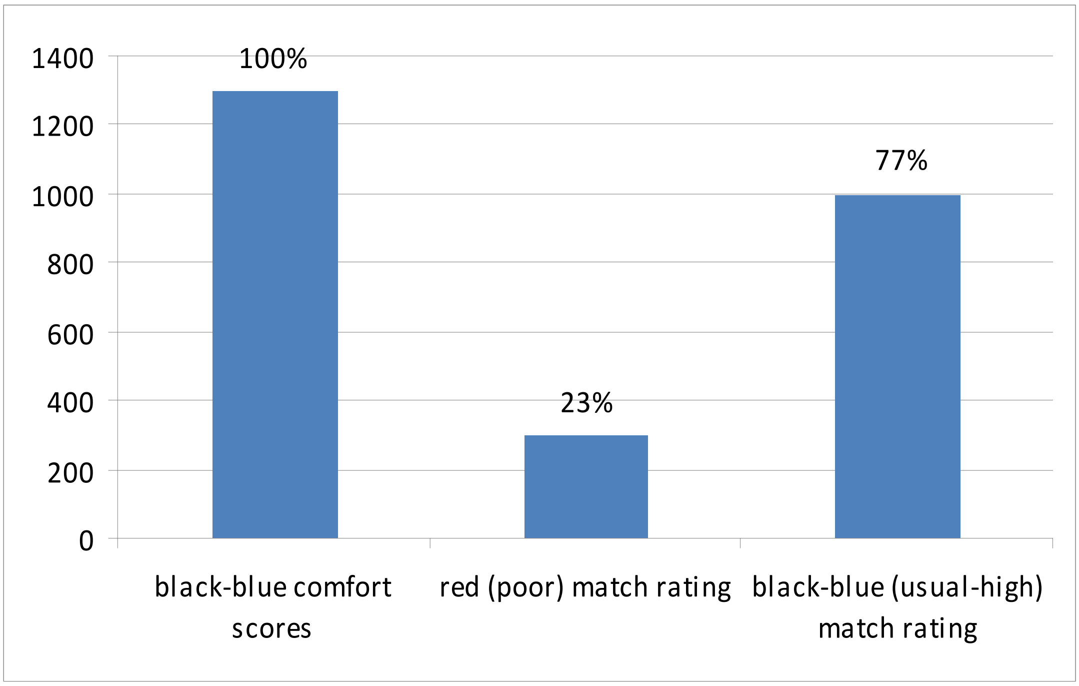


Figure 8.3 shows how usual (black) and high (blue) lower extremity comfort scores were matched to performance ratings. When comfort scores were not considered poor, there was a strong association to usual-good match ratings (77%) and weak relationships to poor match ratings (23%).

These results reinforce the outcomes shown in Figure 8.2 where poor (red) comfort was likely to affect match ratings. When LLCI scores were ranked as usual and high (black-blue) comfort, 23% of occasions were associated with a poor match rating. The inference drawn from these results is while usual high comfort has benefits for performance; factors that affect performance are not only related to lower extremity comfort. The overall results support the research hypothesis that poor (red zone) comfort scores (poor lower extremity comfort) are not well correlated to high rating match performances.

Figure 8.4 *Relation between poor lower extremity comfort and poor performance ratings.*

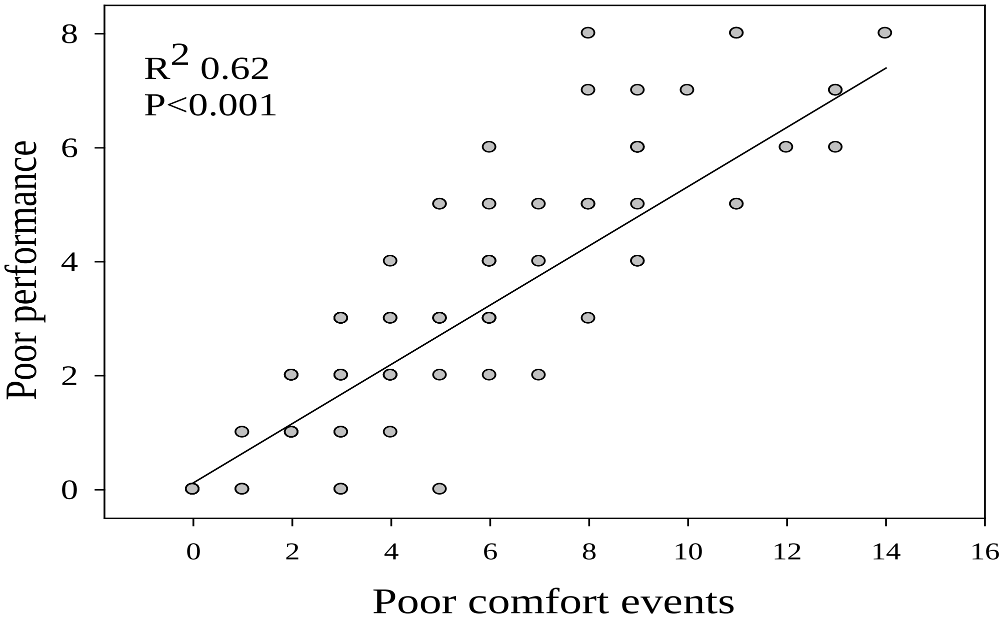


Figure 8.5 *Relation between poor lower extremity comfort and usual (median range) performance ratings.*

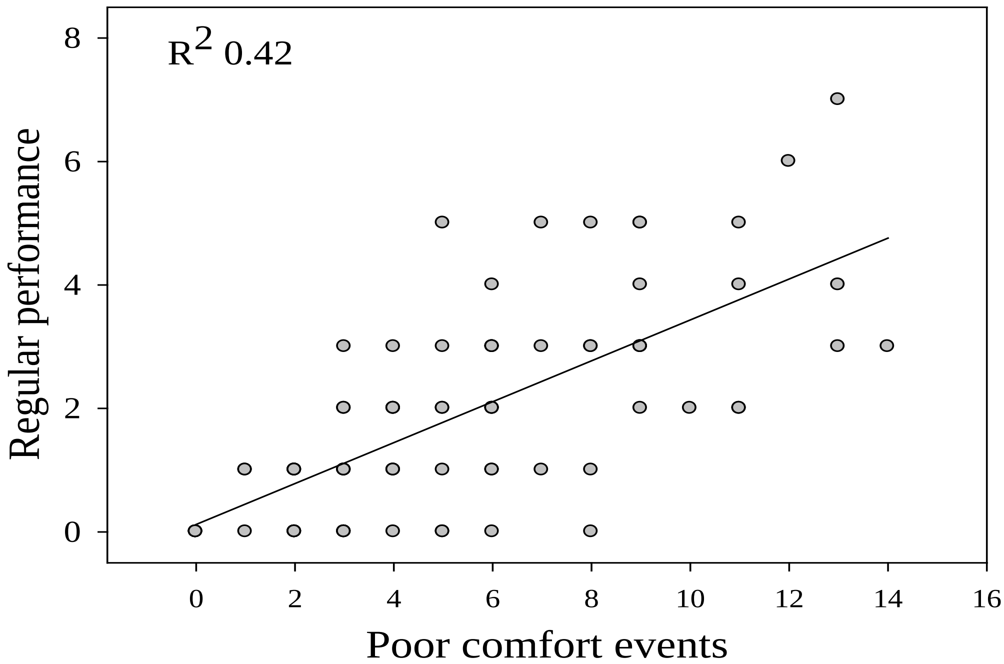
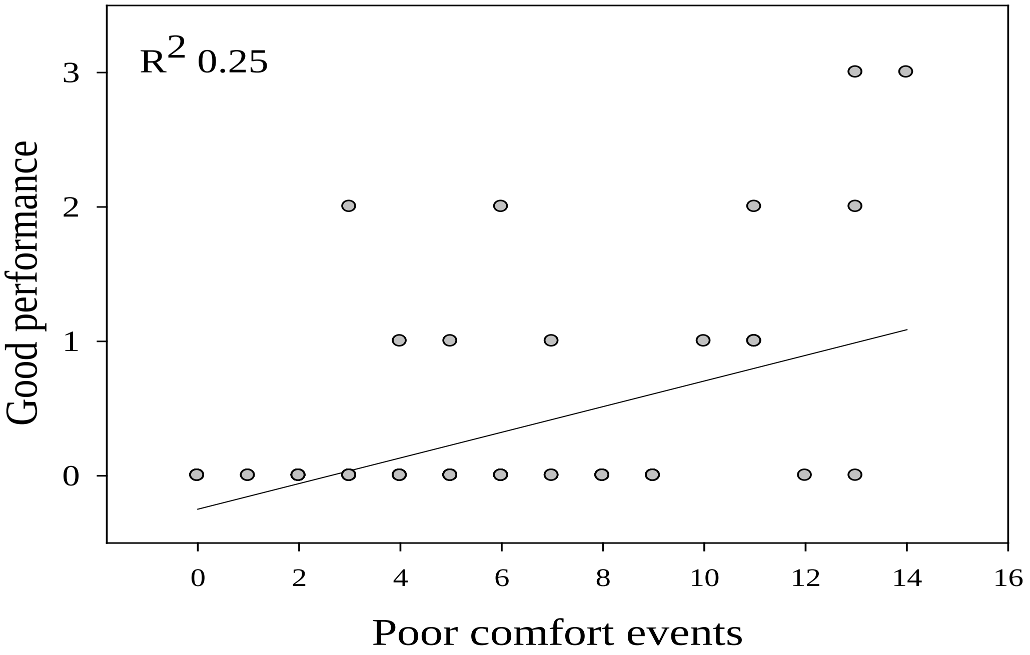


Figure 8.6 *Relation between poor lower extremity comfort and good performance ratings.*



The scatter plots show the spread of zone match ratings (poor [red], regular [black], high [blue] relative to poor lower extremity comfort. Figure 8.4 shows poor comfort was correlated with poor match ratings (R^2 =0.62, P=<0.001) indicating a strong association between poor lower extremity comfort and a poor match rating. In one example, the plot shows a direct relationship between poor (red) comfort (8 events) and poor (red) match ratings (8 events). Conversely, relatively few poor comfort ratings were associated with zero poor match ratings showing the probability of a poor match rating when registering poor lower extremity comfort. However, poor comfort was not well correlated with regular (black) match ratings (R^2 =0.42) and was poorly correlated with good (blue) match ratings (R^2 =0.25) indicating that poor lower extremity comfort is not associated with high match ratings.

As comfort improved, there were an increasing number of zero match rating events, an indication that poor comfort was not associated with better match ratings (Figure 8.5 and 8.6). Figure 8.6 shows a broad scatter of match ratings indicating a weak relationship between high match ratings and poor comfort events. The range of high match ratings was 0-3 for each player, but with a large number of poor comfort events (16 events). The highest high match rating was 3 events which occurred with 13-14 poor comfort events and was indicative of the weak relationship between poor lower extremity comfort and high performance when measured by coach value ratings.

The graphical results are confirmed by statistical evidence. Table 8.1 shows the relation between the number of comfort events and the Match-day ratings. The correlations were highly statistically significant for poor (red) comfort events, less significant for usual (black) comfort events and highly significant for usual and high comfort when combined (black-blue comfort), showing for all classifications that increased comfort events were associated with higher match ratings.

Table 8.1 *Relation between comfort and performance measured as a Match-day rating.*

	Poor (red) match rating	Usual (black) match rating	Good (blue) match rating	Usual and Good (black-blue) rating
Poor (red) comfort scores				
Linear regression R^2	0.62	0.42	0.25	
Pearson Correlation	0.79	0.66	0.50	
P value	<0.0001	<0.0001	<0.0001	
N	79	79	79	
High (blue) comfort scores				
Linear regression R^2	0.08	0.07	0.004	
Pearson Correlation	0.28	0.27	0.20	
P value	0.013	0.018	0.08	
N	79	79	79	
Usual and high (black-blue) comfort scores				
Linear regression R^2	0.48			0.94
Pearson Correlation	0.69			0.97
P value	<0.0001			<0.0001
N	79			79

8.4.3 Case studies of comfort and performance

Tables 8.2 and 8.3 represent case examples of comfort and rated performance data for two squad players from separate football codes who were representative of their respective groups. Scores were given for comfort and rated performance and represent match participation. Where no scores are entered the players were injured and did not participate in the match. There were no differences between the football codes in relation to outcome data, showing the versatility of the LLCI between different codes of football. However, Table 8.3 which represents a footballer in the Super 14 Rugby Competition shows a higher proportion of missed games due a contact injury which is consistent with the rugby codes having more contact injuries than Australian Rules.

8.4.3.1 Case Study A

Table 8.2 *Comfort and rated performance for an Australian Rules player for 26 weeks of football participating in the Australian Football League*

Player	Opposition	Team	Lower Extremity Comfort Score	Match Rating Score	Association Between Comfort and Match Ratings
Name Round 1	xxx	2^{nd} grade	**33**	**19**	High--Good
Name Round 2	xxx	1st grade	**30**	**13**	Usual--Usual
Name Round 3	xxx	1st grade	**30**	**15**	Usual--Usual
Name Round 4	xxx	1st grade	**26**	**14**	Poor--Usual
Name Round 5	xxx	1st grade	**31**	**19**	High--Good
Name Round 6	xxx	1st grade	**30**	**12**	Usual--Poor
Name Round 7	xxx	1st grade	**28**	**17**	Usual--Good
Name Round 8	xxx	1st grade	**27**	**8**	Poor--Poor
Name Round 9	xxx	1st grade	**29**	**14**	Usual--Usual
Name Round 10	xxx	1st grade	**25**	**12**	Poor--Poor
Name Round 11	xxx	1st grade	**29**	**13**	Usual--Usual
Name Round 12	xxx	injured	**xx**	**xx**	No association due to injury
Name Round 13	xxx	injured	**xx**	**xx**	No association due to injury
Name Round 14	xxx	2^{nd} grade	**30**	**14**	Usual--Usual

Player	**Opposition**	**Team**	**Lower Extremity Comfort Score**	**Match Rating Score**	**Association Between Comfort and Match Ratings**
Name Round 15	xxx	2nd grade	**26**	**12**	Poor--Poor
Name Round 16	xxx	1st grade	**29**	**14**	Usual--Usual
Name Round 17	xxx	1st grade	**30**	**15**	Usual--Usual
Name Round 18	xxx	1st grade	**30**	**15**	Usual--Usual
Name Round 19	xxx	1st grade	**30**	**19**	Usual--Good
Name Round 20	xxx	1st grade	**30**	**8**	Usual--Poor
Name Round 21	xxx	1st grade	**27**	**8**	Poor--Poor
Name Round 22	xxxx	1st grade	**24**	**7**	Poor--Poor
Name Round 23	xxx	2nd grade	**28**	**12**	Usual--Poor
Name Round 24	xxx	1st grade	**29**	**14**	Usual--Usual
Name Round 25	xxx	1st grade	**28**	**14**	Usual--Usual
Name Round 26	xxx	1st grade	**31**	**18**	High--Good
		Median score	29.0	14.0	
High comfort (blue zone)	>30	Median + 2 comfort points	Good match rating (blue zone)	>15	
Usual comfort (black zone)	28--30	Median ±1 comfort point	Usual match rating (black zone)	13 - 15	
Poor comfort (red zone)	<28	Median -2 comfort points	Poor match rating (red zone)	<13	

Table 8.2 shows lower extremity comfort and match ratings of a player for each given week over one complete football season. The median lower extremity comfort was 29 $^{\text{comfort points}}$, and median match rating of 14 $^{\text{comfort points}}$ enabling zones to be allocated around the respective median scores. In this example, there was a direct relationship between poor (red) comfort ratings and poor match ratings on five occasions over the period of data collection. The only week in which there was no direct relationship was Round 4. There was also a direct relationship for high (blue zone) comfort and good performance (blue match rating). This was recorded on 4 occasions. For the remaining weeks, usual comfort (black) was registered with generally a regular (black) match rating scored. However, due to variances in performance by a player there will not always be a direct relationship between comfort and ratings. For weeks 6 and 23 black zone (usual) comfort ratings were associated with a red (poor) performance. In week 7, a blue (good) rating was scored.

8.4.3.2 Case Study B

Table 8.3 *Comfort and rated performance for a Super 14 Rugby player for 16 weeks of football.*

Player	Opposition	Team	Lower Extremity Comfort Score	Match Rating Score	Association Between Comfort and Match Ratings
Name Round 1	xxx	1st grade	**34**	**19**	High-- Good
Name Round 2	xxx	1st grade	**34**	**19**	High --Good
Name Round 3	xxx	Injured	**xx**	**xx**	No association due to injury
Name Round 4	xxx	1st grade	**33**	**19**	Usual--Good
Name Round 5	xxx	1st grade	**33**	**17**	Usual--Usual
Name Round 6	xxx	Injured	**xx**	**xx**	No association due to injury
Name Round 7	xxx	1st grade	**34**	**18**	High --Usual
Name Round 8	xxx	Injured	**xx**	**xx**	No association due to injury
Name Round 9	xxx	Injured	**xx**	**xx**	No association due to injury
Name Round 10	xxx	Injured	**xx**	**xx**	No association due to injury
Name Round 11	xxx	1st grade	**33**	**14**	Usual--Poor
Name Round 12	xxx	1st grade	**30**	**15**	Poor--Poor
Name Round 13	xxx	2nd grade	**28**	**15**	Poor--Poor
Name Round 14	xxx	2nd grade	**30**	**15**	Poor--Poor

Player	Opposition	Team	Lower Extremity Comfort Score	Match Rating Score	Association Between Comfort and Match Ratings
Name Round 16	xxx	Injured	**xx**	**xx**	No association due to injury
		Median score	32	17	
High comfort (blue zone)	>33	Median + 2 comfort points	Good match rating (blue zone)	>18	
Usual comfort (black zone)	31--33	Median ±1 comfort point (3 point spread)	Usual match rating (black zone)	16--8	
Poor comfort (red zone)	<31	Median -2 comfort points	Poor match rating (red zone)	<16	

Table 8.3 depicts an elite rugby player whose season was affected by injury. The player sustained six missed games due to a leg injury of a contact nature which never fully recovered during the season. The LLCI registered high comfort and subsequent good rating performances were allocated by the coaching staff to the player early in the season (Rounds1-2). However, a leg injury of a contact nature sustained during training, resulted in six missed matches over the next 14 rounds of football. The table shows that during the mid portion of the season the player returned from injury (Round 4) and registered comfort in the usual range for the individual and scored a good performance rating. However, the player succumbed to the same injury in Round 6, and Rounds 8 -10. On return from injury (Round 11), the player regained his regular 1^{st} Grade spot, but rated performances were poor during Rounds 11 and 12. The consequence of poor performances and poor lower extremity comfort was the inability to compete at the higher intensity levels associated with 1^{st} Grade football. This case study was considered to be

representative of others within the cohort that highlights an association between lower extremity musculoskeletal comfort and performance.

8.5 DISCUSSION

This is the first study to assess the relationship between lower extremity comfort rated Match-day performances. Rated performance measures are commonly used within professional sport to monitor tasks such as skill execution, intensity, adaptability to the game being played, and attention to game plan. The importance of performance measures for football success is based upon a player and team collectively out-performing opponents. Thus measures of performance and programs to prevent and address comfort and injury may be of importance for individual and team success.

A paradigm not widely tested that has been examined throughout this thesis is poor lower extremity comfort will affect running and football skills which may subsequently compromise performance criterion. While it is acknowledged many factors will affect performance, it is surprising that greater attention has not been given to measures of musculoskeletal comfort and their effect on performance.

Training routines within professional football comprise a variety of different programs intended to maintain or improve fitness, to improve skills or to use as selection training. Players returning from an injury event may not be able to participate in full regular sessions, may be time limited or be required to participate in modified training drills such as “off legs” or stationary skills. The benefits derived from a modified program cannot be considered the same as participation in a full regular training session. The limited training routines will affect performance criterion needed for football skill execution.

One of the challenges for conditioning staff of football organizations is how to deal with poor lower extremity comfort prior to Match-day events. Unlike lower extremity discomfort following Match-day which can be modified with numerous intervention strategies such as modification of training programs, massage, medical intervention and the passage of time, there are limited intervention strategies that exist when poor lower extremity comfort is identified 24 hours before Match-day.

Chapter 4 highlighted how lower extremity comfort will change over the period of a training week (Kinchington, et al., 2010). Lower extremity comfort increases over the period of a training week and generally is higher prior to Match-day compared to the beginning of the training week. The end of a regular training week generally involves a taper period in which the body is not subjected to high loads of physical stress. Therefore lower extremity comfort will theoretically improve and be denoted by higher end of week (Match-day) comfort ratings. Poor Match-day comfort may be due to a player sustaining an injury prior to the game or due to weekday comfort not resetting to median or usual patterns of comfort. In this study, poor lower extremity comfort had a significant association with Match-day rated performance (Figure 8.6; R^2 =0.25). However, it is acknowledged there will not always be a perfect relationship between lower extremity comfort and match ratings. Figure 8.3 shows that for 250 player weeks, usual-high comfort scores resulted in poor (red) match ratings, but was not statistically significant. This was considered normal due to multiple factors affecting a player’s ability to perform well, including factors not involving the status of lower extremity comfort. Data points which were not included in the final analysis due to their biasing statistical results, in favour of the research hypothesis, involved two players whose comfort results were outliers and whose data were not representative of the cohort because of known medical conditions. The two footballers' recorded more than 15 poor (red zone) comfort events from a possible 18 and 20 weeks respective participation. The comfort data scores were significantly outside the upper 25% whisker range for poor comfort events shown in Figure 8.1. In these cases not only was poor lower extremity comfort associated with poor Match-day rated performance scores, but also recorded poor comfort early in the training week. These players registered poor lower extremity comfort consistently due to chronic degenerative lower extremity musculoskeletal conditions. Such information has relevance to clinicians who deal with chronic injuries because the example provides a snapshot of the many facets of a football cohort and the many factors which will affect a players comfort and potentially subsequent rated performance. It is therefore of clinical relevance to establish tools, such as the LLCI, to monitor not only group data but also all individual players so that effective intervention strategies can be applied.

The application of this study is the use of lower extremity comfort measures to assist in decision making on the potential playing status of an individual. In this study, we showed that when a player lower extremity comfort is below a median or usual comfort range, performance was compromised (60%, $P<0.001$). However, the reverse situation is not necessarily consistent. When lower extremity comfort is high, performance can still be poor; which is due to the many factors to effect performance. It is anticipated this data will be readily applicable to the athlete, coaches and conditioning staff on how to manage individuals. These results are consistent with other research which indicated a state of comfort is beneficial to reduce muscular fatigue and injury (Mündermann, et al., 2003a; Wakeling, et al., 2002).

The comfort index used in this study, which has been previously validated for injury measures, has the capacity to be used as a valid and responsive instrument to assess rated performance criteria in football. This outcome has important characteristics for future use in research and in clinical practice. The generalisation of this study is limited by the fact it was conducted with two football teams from different codes. Further, outcome results will be affected by factors such as the time comfort data is collected. Comfort will change with time (Chapter 4). Therefore, for Match-day ratings lower extremity comfort should be collected as close to match time as possible. In preparation for the series of studies which forms this thesis, a pilot study which collected comfort data was conducted. The results did not form a part of the overall thesis. The data indicated that when comfort data were collected on Match-day, generally two hours pre start of match, there was a lack of compliance by players in provision of data, the coaching staff were not supportive and comfort responses were often erroneous. Frequently, players provided an exaggerated comfort score because of psycho-physiological effects such as adrenaline and pain inhibiting agents and many did not register comfort data. The collection of data the day of the match was a significant imposition upon the players. In the current study, the data was collected 24-30 hours before match time and the data were reliable as shown in a previous study (Chapter 4) with absolute differences in comfort scores between 0^{hours} and 24^{hours} varying only between $0.21^{\text{comfort points}}$ and $0.37^{\text{comfort points}}$.

However, time periods greater than 24 hours will produce significant variations in comfort scores.

The application of the methodology described in this study has relevance to other sports and also to youth and amateur sports where the level of medical care and conditioning science is not typically as good. The LLCI extends previous studies in this field by highlighting the importance of lower extremity comfort to an individual in relation to perceived performance. Because the system collects prospective data on lower extremity comfort, the implementation of it requires a health belief model for successful use (Conner & Norman, 1996). In a health belief model, education about the negative consequences of not paying attention to lower extremity discomfort need to be accepted and then the players have to want to avoid these consequences. The belief in the LLCI would then be confirmed by players using it as a means to proactively avoid serious injuries and impaired performance.

8.6 CONCLUSIONS

This study examined the hypothesis that poor lower extremity comfort as measured by the LLCI was not correlated with high match ratings. The LLCI is the first measurement tool to investigate a relationship between comfort and rated performance. The main advantages of the LLCI are its ease of implementation, the clarity of the information collected and most importantly, the direct clinical application of the information to the performance of individual players. The categorization of players into high and low comfort groups for any given week will facilitate critical clinical decisions about intervention strategies to improve player lower extremity comfort prior to Match-day. Such decisions are likely to have a major influence on player performance.

CHAPTER NINE

CONCLUSIONS AND RECOMMENDATIONS

9.1 CONCLUSIONS

The thesis addressed one of the most common issues in running-based team sports; the high incidence of lower extremity injury. A series of studies explored a strategy to add another level of monitoring and management to the sports injury paradigm. Despite efforts of researchers and health professionals to implement the van Mechelen model (1992) and modifications to the model (Figure 1.2), ongoing endeavours to understand more about lower extremity injury remain highly prioritised.

Specifically, this research involves investigating risk factors, understanding epidemiology, conducting intervention programs and exploring preventative strategies. The unresolved nature of sports injury research is due to the many variables that confound efforts to conquer risk factors and the multiple confounders to the implementation of intervention programs.

The thesis comprised six peer-reviewed studies and highlights lower extremity comfort measures as viable. The comfort paradigm using self-rating measures permeates areas of biomechanics, footwear, military, and clinical medicine, but results of the systematic review (Chapter 2) indicated comfort is infrequently used in evaluation of sports injury. The lack of comfort research into football was surprising because differences in comfort as small as 10% may have clinical relevance (Davis, et al., 2008).

Germane to all football codes are the high volumes of running. Distances recorded in the various codes have recorded footballers running upward 7 kilometres (km) in the rugby codes (Cunniffe, et al., 2009), 12 km in football-soccer (Rampinini, et al., 2007) and in a range of 13 km in Australian Rules (Gray & Jenkins, 2010) to 16.6 km per game (Burgess & Naughton, 2003). As a consequence, the high demands on the musculoskeletal region, particularly the lower extremity, which has injury prevalence as high as 80% (Martin Hagglund, et al., 2007) require pre-emptive measures to monitor lower-extremity well-being.

The development of the LLCI (Chapter 3) explored the capacity of an instrument to simultaneously measure five anatomical regions of the lower extremity and footwear. The instrument showed good trait construct for ease of use and suitability in a football environment. The outcomes of the study provided confidence to test the LLCI in a wider cohort of professional footballers under different conditions that would have relevance to training and match day conditions. Professional footballers (N=63) in two codes tested the LLCI in training and match day conditions. Measures of lower limb comfort in different environments (weekday training and match day playing) over multiple weeks supported the reliability of the LLCI (Chapter 4).

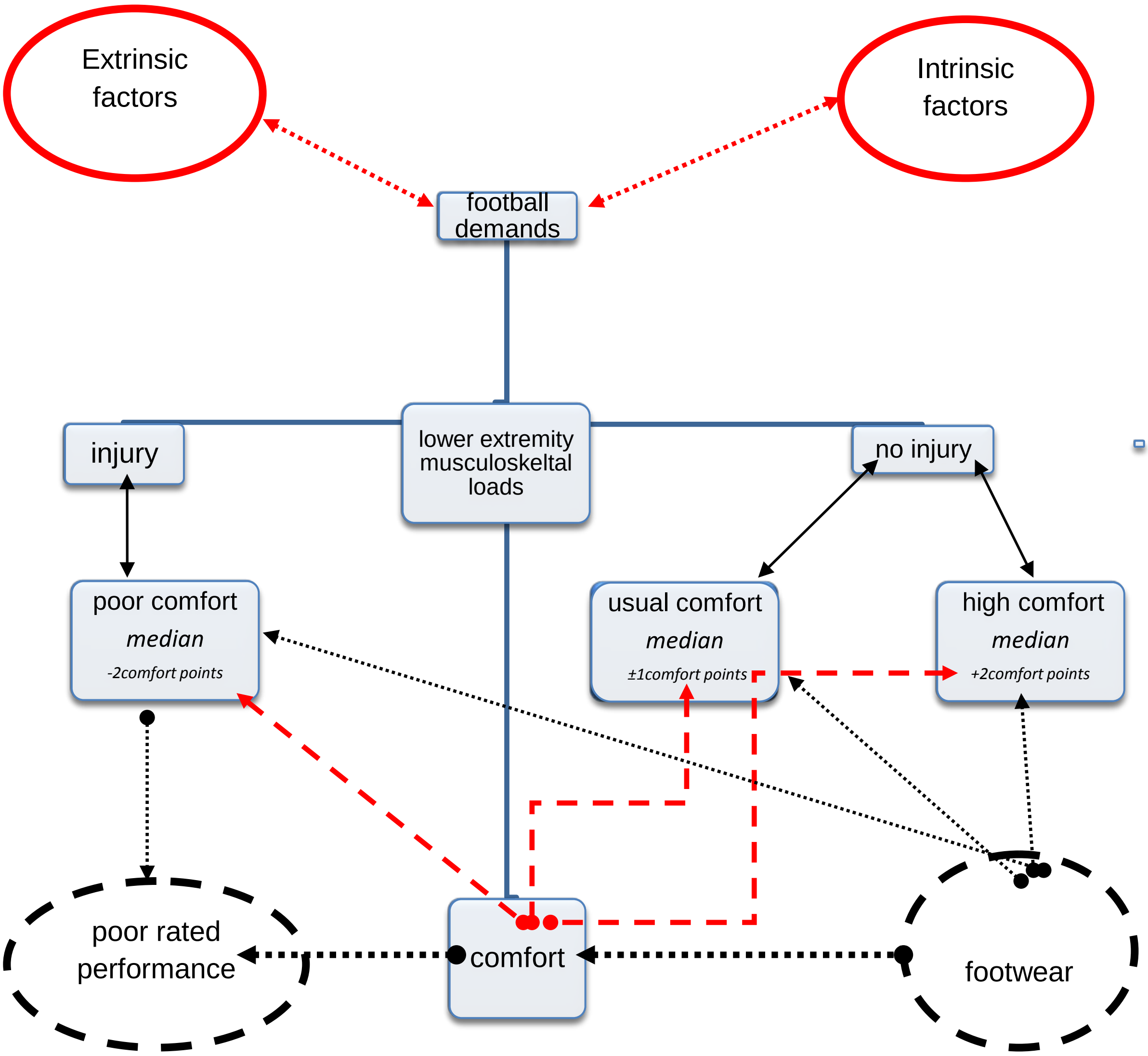
An extension of the reliability study was to investigate the sensitivity of the LLCI and the role of comfort in injury. Three codes of football comprising 182 footballers were followed for one full season of football in which weekly measures of lower extremity comfort were taken and compared with injury (Chapter 5). Three comfort zones (poor, usual and high) provided a mechanism to prospectively catalogue individual lower extremity status for any given period of time. The benefit of establishing zone comfort was to allow for fluctuations in player comfort for any given time period. The results indicated a strong relationship between poor lower limb comfort and injury (*time loss event)*. Lower extremity comfort in the cohort of footballers fluctuated throughout the season. The results of the study confirmed that comfort changes are relevant to football, that comfort zones can be either predictive of an injury (*time loss event) or* used to monitor lower extremity well-being. The clinical interpretation of the results was that high comfort scores may be a protective mechanism for lower limb injury.

Specific to football, footwear is the only form of player apparel that acts as a filter between the ground surface and the body, that will directly influence movement patterns on a variety of surfaces (soft, hard, wet, dry and undulating), and therefore contribute to a number of football outcomes (slipping, performance, traction, comfort, injury). However, no footwear profiling studies have assessed footwear selection decisions, and the subsequent potential associations between footwear, injury and comfort within the football codes. Two footwear intervention studies were conducted. The first study (Chapter 6) examined the effectiveness of a tailored footwear program on lower limb comfort in two different football organisations competing in the NRL. The second study (Chapter 7) investigated the effect of a training shoe within the one football organisation. The reason footwear was examined is the large body of research relative to injury and performance (Lambson, Barnhill, & Higgins, 1996; McNitt, Waddington, & Middour, 1997; Milburn & Barry, 1998). The outcome measures of relations between footwear and comfort and comfort and injury indicated that a tailored footwear program (consisting of player education, prescription of footwear and frequent rotation of footwear), resulted in a lower incidence of injury and higher comfort ratings compared with a program of usual athlete footwear practices.

A paradigm not widely tested relevant to football is that poor lower limb comfort will affect running and football skills and compromise on-field performance. Pragmatically a link between injury and performance is clear; however there was limited scientific data to support this hypothesis. The final study in the thesis, examined the links between comfort and rated performance (Chapter 8). The results showed that poor lower limb comfort is not well correlated to high-rated performances.

To reiterate, the introduction chapter in this thesis proposed a model in which the LLCI may contribute to injury management. The outcomes derived from the thesis enabled the theoretical model constructed (Figure 1.2) to develop into a clinical model directly arising from the studies within the thesis (Figure 9.1).

Figure 9.1 *Schematic model of football demands upon lower extremity musculoskeletal loads and the how comfort measures (poor, usual and high) affect injury and rated performance.*



In summary, the tested hypotheses in this thesis were:

I. A tool to measure changes in lower extremity limb comfort over time in a competitive football environment can be developed and prove reliable (Chapters 3 and 4).

II. The LLCI provides results associated with injury and perceived performance (Chapters 5 and 8).

III. A tailored footwear program with professional footballers is effective in generating positive comfort and injury outcome measures (Chapters 6 and 7).

All the hypotheses that the thesis examined were supported in six peer reviewed publications (page VIII). The outcomes of the studies combine to demonstrate a number of central findings that provide an overall snapshot of the results. The results of the studies provide confidence that a new instrument for monitoring athletes has been developed and could be involved in future research and clinical practice.

9.2 THE CENTRAL FINDINGS OF THE STUDY

I. The LLCI was a novel instrument to measure lower extremity comfort. The LLCI demonstrated good responsiveness among professional footballers to suitability (McNemars test, P=0.019) and ease of use (McNemars test, P<0.01) in a specific football environment.

II. The LLCI was a reliable measure of lower extremity comfort in two professional football environments; training week (ICC 0.99) and match day (ICC 0.97). Lower extremity comfort was responsive to passage of time. Comfort measures for differences (within player) were not significant for periods 0 ^{hours} and 8 ^{hours} (P>0.05), but significant for time periods 0-24 ^{hours} and periods of more than 24 ^{hours} (P<0.05). The results promote the use of the LLCI in footballers over a relatively prolonged period after an event such as intensive training or competitive games.

III. Lower extremity comfort can be classified into three zones (high, usual and poor comfort) to act as a barometer of individual musculoskeletal comfort. For 182 footballers participating in three codes of football, the LLCI demonstrated high criterion-related validity for the relationship between comfort and injury. Poor lower limb comfort was highly correlated to injury (R^2 =0.77) and accounted for 43.5 *time loss events* / 1000 hrs football exposure. Injury measures as *time loss events* was not significant with usual comfort (R^2 = 0.48) or high (R^2 =0.15) lower extremity comfort.

IV. The LLCI can be utilized as a predictor of injury (*time loss events* ^{TLE}). A predicted *time loss event* (Predicted ^{TLE}) was defined as an injury occurring during the football week following the recording of poor comfort (Predicted ^{TLE} = LLCI $^{\text{data pre injury}}$). Poor comfort was predictive of injury 47% of all *time loss events*.

V. A tailored footwear program consisting of player education, prescription of footwear and frequent rotation of footwear, resulted in a lower incidence of injury and higher comfort ratings. The results of an inter-club study of professional rugby league teams indicated the tailored footwear group had a reduced incidence of lower limb injury (P=0.005), better lower extremity comfort ratings (P<0.001) and reduced injuries/1000 hrs (24.79/1000) compared with the competitive league-matched team that did not use a tailored footwear program. An extension study compared the use of a specific training shoe to regular football boots. The use of a training shoe over a 30 week period resulted in fewer *time loss events* (1.7 v 3.9), increased training participation (P<0.0001) and matches (P=0.002).

VI. Individual football rated performance measures were correlated with lower extremity comfort. A footballer with poor lower extremity comfort generally did not perform well in a match situation. Poor lower limb comfort and good match day rated performance were not well correlated (R^2= 0.25, P=<0.001) in the group of footballer assessed (N= 79), while footballers with usual-high lower extremity comfort recorded usual-good rated performance by their coaches (R^2= 0.69, P=<0.001).

9.3 STRENGTHS OF THE STUDY

I. The study was a novel approach to lower limb injury research. Psycho-physiological comfort ratings have been used in professions such as nursing (Kolcaba & Fisher, 1996) and military (Birrell & Haslam, 2009) as well as some areas of physical activity (Mundermann, et al., 2003b) to assess footwear comfort. This series of studies is the first to employ comfort as a concept in sport relevant to lower extremity injury.

II. The study extended previous football injury investigation via the development of high and low comfort zones around a median comfort score to examine the relationship between comfort, injury, and rated performance. The concept of lower limb comfort has important relevance for future use in research and in clinical practice. High comfort scores can be interpreted as a protective mechanism for lower limb injury.

III. The study demonstrated the use of a LLCI for clinicians and athletes to:

   a. prospectively monitor lower limb comfort at multiple anatomical regions,
   b. create a baseline for comfort norms for individual players for future assessment,
   c. to use prospectively in the event of early injury detection
   d. to monitor rehabilitation progress.

IV. The design of the study was sensitive in assessing comfort in a large group of professional footballers (N=182) by cataloguing fluctuating comfort scores and establishing comfort zones for individuals to monitor lower extremity comfort. The strengths of the design included the broad external validity encompassing three codes of football at the elite level of participation. The implementation of the LLCI as an instrument to collect data demonstrated the non-invasive nature of the study when professional footballers had many demands placed upon their time, and the capacity of the LLCI to be easily transferable between football facilities.

V. A further strength of the study was the capacity to prospectively record comfort. When an injury occurs, a discomfort event can be compared to a catalogue of comfort experiences (baseline comfort), providing a measure of the severity of the injury. Such information and recall is currently not possible with reactive pain scales if there is no injurious experience on which to draw.

VI. The thesis was the first to assess footwear intervention programs in professional footballers with results highlighting the benefits of a tailored footwear program that may have protective qualities for the lower limb.

VII. It is anticipated the findings of the studies in the thesis will be useful to medical advisers involved in other running-based team sports who can now consider adding footwear comfort as a possible contributor to injury prevention.

VIII. The information derived from the results proposes challenges for future studies. The confidence to implement a lower extremity monitoring tool provided the opportunity to investigate associations between comfort and injury and comfort and rated-performance. The significance of the comfort data will enable further investigation of injury and performance aspects of football and other physical activities.

9.4 OUTCOME LIMITATIONS OF THE STUDY

I. Randomized controlled trials are recognised as strong clinical evidence of effectiveness. The current study was a field-based, non-randomised controlled trial. Field based studies present many challenges to randomised control trials, particularly among professional football. Thus many factors remain outside the control of researchers. Nevertheless, the proof of concept presented for the LLCI in the studies encompassing this thesis, provide grounding for future, common higher order research.

II. The current studies were restricted to professional level football codes. The results from the studies may lack external validity, to community based levels of sporting participation. However, injuries remain more debilitating and expensive among professional athletes than amateur participants. Thus the findings from this thesis have greatest relevance to elite athletes. This does not preclude the outcomes of this research being applied or modified for use with less structured levels of sporting participation.

9.5 RECOMMENDATIONS

I. This study shows the use of a lower limb comfort index is a reliable instrument to record lower limb comfort in a football environment. It is recommended that use of the LLCI has application beyond football codes to other running-based weight bearing sports. It is also recommended that results are disseminated to clinical practice for general physicians, physiotherapists, podiatrists and those engaged in the management of lower limb musculoskeletal injury.

II. A coordinated footwear program can be beneficial in the injury management paradigm. Ultimately, optimal footwear selection based on player comfort guidelines is recommended for development to assist injury prevention programs.

III. Lower limb comfort can be affected by footwear with important consequences for injury management and player welfare. This research provided evidence that the football boot when worn for extended periods contributes to poor lower limb comfort and that a dedicated training shoe may offer protection to players over the course of the season. A platform to develop clinical footwear guidelines and educative programs to footballers, coaching staff and medical personnel is recommended.

CHAPTER TEN

REFERENCES

Altman, D., & Dore, C. (1990). Randomisation and baseline comparisons in clinical trials. *The Lancet, 335*(8682), 149-153.

American Academy of Podiatric Sports Medicine (2010). Retrieved 20 February, 2010, from http://www.aapsm.org/

American College of Sports Medicine (2010). Retrieved 20 February, 2010, from http://www.acsm.org/

American Physical Therapy Association (2010). Retrieved 20 February, 2010, from http://www.apta.org/

Anderson, B. C., Stefanyshyn, D. J., & Nigg, B. M. (2005). *The effect of moulded footbeds on comfort and injury rate in military combat boots.* Paper presented at the ISB Technical Group on Footwear Biomechanics, 7th Symposium on Footwear Biomechanics, Clevland Ohio.

Apriantono, T., Nunome, H., Ikegami, Y., & Sano, S. (2006). The effect of muscle fatigue on instep kicking kinetics and kinematics in association football. *Journal of Sports Sciences, 24*(9), 951-960.

Arnason, A., Sigurdsson, S. B., Gudmundsson, A., Holme, I., Engebretsen, L., & Bahr, R. (2004). Risk factors for injuries in football. *The American Journal of Sports Medicine 32*(1), 5-16.

Au, E. Y. L., & Goonetilleke, R. S. (2007). A qualitative study on the comfort and fit of ladies' dress shoes. *Applied Ergonomics, 38*(6), 687-696.

Babic, Z., Misigoj-Durakovic, M., Matasic, H., & Jancic, J. (2001). Croatian rugby project. Part II: Injuries. *Journal of sports medicine and physical fitness, 41*(3), 392-398.

Baczkowski, K., Marks, P., Silberstein, M., & Schneider Kolsky, M. (2006). A new look into kicking a football: an investigation of muscle activity using MRI. *Australasian Radiology, 50*(4), 324-329.

Bahr, R., & Holme, I. (2003). Risk factors for sports injuries—a methodological approach. *British Journal of Sports Medicine, 37*(5), 384.

Bahr, R., & Krosshaug, T. (2005). Understanding injury mechanisms: a key component of preventing injuries in sport. *British Journal of Sports Medicine, 39*(6), 324-329.

Bartold, S. (1999). The football boot, saint or sinner? *Journal of Science and Medicine in Sport, 2*(1), 26-27.

Benner, P. (1982). From novice to expert. *AJN The American Journal of Nursing, 82*(3), 402-407.

Bennett, P. J., Patterson, C., & Dunne, M. P. (2001). Health-related quality of life following podiatric surgery. *Journal of the American Podiatric Medical Association, 91*(4), 164-173.

Bentley, J., Ramanathan, A., Arnold, G., Wang, W., & Abboud, R. (2010). Harmful cleats of football boots: a biomechanical evaluation. *Foot and Ankle Surgery, In Press*.

Birrell, S. A., & Haslam, R. A. (2009). Subjective skeletal discomfort measured using a comfort questionnaire following a load carriage exercise. *Military Medicine, 174*(2), 177-182.

Bishop, M., Fiolkowski, P., Conrad, B., Brunt, D., & Horodyski, M. B. (2006). Athletic footwear, leg stiffness, and running kinematics. *Journal of athletic training, 41*(4), 387-392.

Bland, J. M., & Altman, D. G. (1996). Measurement error. *British Medical Journal, 313*(7059), 744.

Boonstra, A. M., Schiphorst Preuper, H. R., Reneman, M. F., Posthumus, J. B., & Stewart, R. E. (2008). Reliability and validity of the visual analogue scale for disability in patients with chronic musculoskeletal pain. *International Journal of Rehabilitation Research, 31*(2), 165-169.

Brewer, J. and Davis, J. (1995) Applied physiology of rugby league. *Sports Medicine*, *20*, 129-135.

Brooks, J., Fuller, C., Kemp, S., & Reddin, D.B. (2005). A prospective study of injuries and training amongst the England 2003 Rugby World Cup Squad. *British Journal of Sports Medicine,39, 288-293*

Brooks, J.H.M., Fuller, C.W., Kemp, S.P.T., & Reddin, D.B. (2008). An assessment of training volume in professional rugby union and its impact on the incidence, severity, and nature of match and training injuries. *Journal of Sports Sciences*, *26*, 863-873.

Burgess, D., & Naughton, G. (2003). Quantifying the gap between under 18 and senior AFL football. *J Sci Med Sport, 6*(4), 525.

Burns, J., Keenan, A. M., & Redmond, A. C. (2003). Factors associated with triathlon-related overuse injuries. *The Journal of orthopaedic and sports physical therapy, 33*(4), 177-184.

Butler, R. J., Davis, I., & Hamill, J. (2005). *The effect of motion control and cushioning shoes on high and low arched runners.* Paper presented at the

ISB Technical Group on Footwear Biomechanics, 7th Symposium on Footwear Biomechanics Clevland, Ohio.

Byrne, C., Twist, C., & Eston, R. (2004). Neuromuscular function after exercise-induced muscle damage: theoretical and applied implications. *Sports Medicine, 34*(1), 49-69.

Cannell, L., Taunton, J., Clement, D., Smith, C., & Khan, K. (2001). A randomised clinical trial of the efficacy of drop squats or leg extension/leg curl exercises to treat clinically diagnosed jumper's knee in athletes: pilot study. *British Journal of Sports Medicine, 35*(1), 60-64.

Cavanagh, P. R., & Lafortune, M. A. (1980). Ground reaction forces in distance running. *Journal of Biomechanics, 13*(5), 397-406.

Cham, R., & Redfern, M. S. (2001). Effect of flooring on standing comfort and fatigue. *Human Factors: The Journal of the Human Factors and Ergonomics Society, 43*(3), 381-391.

Che, H., Nigg, B., & De Koning, J. (1994). Relationship between plantar pressure distribution under the foot and insole comfort. *Clinical Biomechanics, 9*(6), 335-341.

Cheung, K., Hume, P. A., & Maxwell, L. (2003). Delayed onset muscle soreness: treatment strategies and performance factors. *Sports Medicine, 33*(2), 145-164.

Cheung, R. T. H., & Ng, G. Y. F. (2010). Motion control shoe delays fatigue of shank muscles in runners with overpronating feet. *American Journal of Sports Medicine, 38*(3), 486-491.

Chiu, M. C., & Wang, M. J. J. (2007). Professional footwear evaluation for clinical nurses. *Applied Ergonomics, 38*(2), 133-141.

Chomiak, J., Junge, A., Peterson, L., & Dvorak, J. (2000). Severe injuries in football players. *The American Journal of Sports Medicine, 28*(Supp 5), 58-68.

Clinghan, R., Arnold, G. P., Drew, T. S., Cochrane, L. A., & Abboud, R. J. (2008). Do you get value for money when you buy an expensive pair of running shoes? *British Journal of Sports Medicine, 42*(3), 189-193.

Collie, A., Maruff, P., Makdissi, M., McCrory, P., McStephen, M., & Darby, D. (2003). CogSport: reliability and correlation with conventional cognitive tests used in postconcussion medical evaluations. *Clinical Journal of Sport Medicine, 13*(1), 28-32.

Collinge, R., & Simmonds, J. V. (2009). Hypermobility, injury rate and rehabilitation in a professional football squad: a preliminary study. *Physical Therapy in Sport, 10*(3), 91-96.

Collins, J., & Whittle, M. (1989). Impulsive forces during walking and their clinical implications. *Clinical Biomechanics, 4*(3), 179-187.

Conner, M., & Norman, P. (1996). *Predicting health behaviour: Research and practice with social cognition models*: Buckingham: Open University Press.

Coutts, A. J., & Duffield, R. (2010). Validity and reliability of GPS devices for measuring movement demands of team sports. *Journal of Science and Medicine in Sport, 13*(1), 133-135.

Cowan, D. N., Jones, B. H., Frykman, P. N., Polly, D. W. J., Harman, E. A., Rosenstein, R. M., et al. (1996). Lower limb morphology and risk of overuse injury among male infantry trainees. . *Medicine Science Sports & Exercise 28*(8), 945-952.

Cross, K., Worrell, T., Leslie, J., & Van Veld, K. (2002). The relationship between self-reported and clinical measures and the number of days to return to sport following acute lateral ankle sprains. *The Journal of Orthopaedic and Sports Physical Therapy, 32*(1), 16-23.

Crowell, H. P., & Davis, I. S. (2011). Gait retraining to reduce lower extremity loading in runners. *Clinical Biomechanics, 26*(1), 78-83.

Cunniffe, B., Proctor, W., Baker, J. S., & Davies, B. (2009). An evaluation of the physiological demands of elite rugby union using global positioning system tracking software. *The Journal of Strength & Conditioning Research, 23*(4), 1195-1203.

Davis, I. S., Zifchock, R. A., & DeLeo, A. T. (2008). A comparison of rearfoot motion control and comfort between custom and semicustom foot orthotic devices. *Journal of the American Podiatric Medical Association, 98*(5), 394-403.

Dennis, A. J., Finch, C. F., McIntosh, A. S., & Elliott, B. C. (2008). Use of field-based tests to identify risk factors for injury to fast bowlers in cricket. *British Journal of Sports Medicine, 42*(6), 477-482.

Dijkers, M., Kropp, G., Esper, R., Yavuzer, G., Cullen, N., & Bakdalieh, Y. (2002). Reporting on reliability and validity of outcome measures in medical rehabilitation research. *Disability & Rehabilitation, 24*(16), 819-827.

Dillard, J. N., & Knapp, S. (2005). Complementary and Alternative Pain Therapy in the Emergency Department. *Emergency Medicine Clinics of North America, 23*(2), 529-549.

Downie, W., Leatham, P., Rhind, V., Wright, V., Branco, J., & Anderson, J. (1978). Studies with pain rating scales. *Annals of the Rheumatic Diseases, 37*(4), 378-381.

Drawer, S., & Fuller, C. W. (2002). Evaluating the level of injury in English professional football using a risk based assessment process. *British Journal of Sports Medicine, 36*(6), 446-451.

Duffey, M. J., Martin, D. F., Cannon, D. W., Craven, T., & Messier, S. P. (2000). Etiologic factors associated with anterior knee pain in distance runners. *Medicine & Science in Sports & Exercise, 32*(11), 1825-1832.

Dvorak, J., & Junge, A. (2000). Football injuries and physical symptoms: a review of the literature. *American Journal of Sports Medicine, 28*(Supp 5), 3-9.

Dvorak, J., Junge, A., Chomiak, J., Graf-Baumann, T., Peterson, L., Rosch, D., et al. (2000). Risk factor analysis for injuries in football players. Possibilities for a prevention program. *The American Journal of Sports Medicine 28*(Supp 5), 69-74.

Eich, E., Reeves, J. L., Jaeger, B., & Graff-Radford, S. B. (1985). Memory for pain: relation between past and present pain intensity. *Pain, 23*(4), 375-380.

Elleuch, M., Guermazi, M., Mezghanni, M., Ghroubi, S., Fki, H., Mefteh, S., et al. (2008). Knee osteoarthritis in 50 former top-level soccer players: a comparative study. *Annales de Readaptation et de Medicine Physique, 51*(3), 174-178.

Engebretsen, A. H., Myklebust, G., Holme, I., Engebretsen, L., & Bahr, R. (2008). Risk factors for ankle, knee, hamstring and groin injuries among male football players: a prospective cohort study. *British Journal of Sports Medicine, 42*(6), 493-494.

Engebretsen, L., & Bahr, R. (2005). An ounce of prevention? *British Journal of Sports Medicine, 39*(6), 312-313.

English, I. (1993). Intuition as a function of the expert nurse: a critique of Benner's novice to expert model. *Journal of Advanced Nursing, 18*(3), 387-393.

Engström, B., Johansson, C., & Tornkvist, H. (1991). Soccer injuries among elite female players. *The American Journal of Sports Medicine, 19*(4), 372-375.

Finch, C. (2006). A new framework for research leading to sports injury prevention. *Journal of Science and Medicine in Sport, 9*(1-2), 3-9.

Finch, C. (2009). The preventing Australian football injuries with exercise (PAFIX) study: A group randomised controlled trial. *Injury Prevention, 15*(3), 207-207.

Fuller, C., Laborde, F., Leather, R., & Molloy, M. (2008). International rugby board rugby world cup 2007 injury surveillance study. *British Journal of Sports Medicine, 42*(6), 452-459.

Fuller, C. W., Ekstrand, J., Junge, A., Andersen, T. E., Bahr, R., Dvorak, J., et al. (2006). Consensus statement on injury definitions and data collection procedures in studies of football (soccer) injuries. *Scandinavian Journal of Medicine & Science in Sports, 16*(2), 83-92.

Gabbe, B. J., Finch, C. F., Wajswelner, H., & Bennell, K. L. (2004). Predictors of lower extremity injuries at the community level of Australian football. *Clinical Journal of Sport Medicine, 14*(2), 56-63.

Gabbett, T., King, T., & Jenkins, D. (2008). Applied physiology of rugby league. *Sports Medicine, 38*(2), 119-138.

Gabbett, T., Minbashian, A., & Finch, C. (2007). Influence of environmental and ground conditions on injury risk in rugby league. *Journal of Science and Medicine in Sport, 10*(4), 211-218.

Gabbett, T. (2000). Incidence, site, and nature of injuries in amateur rugby league over three consecutive seasons. *British Journal of Sports Medicine, 34*(2), 98-103.

Gabbett, T. (2006a). Performance changes following a field conditioning program in junior and senior rugby league players. *Journal of Strength & Conditioning Research, 20*(1), 215-221.

Gabbett, T. (2006b). Skill-based conditioning games as an alternative to traditional conditioning for rugby league players. *The Journal of Strength & Conditioning Research, 20*(2), 306-315.

Gabbett, T., & Godbolt, R. J. B. (2010). Training injuries in professional rugby league. *The Journal of Strength & Conditioning Research, 24*(7), 1948-1953.

Gaunt, & O'Neill (2007). Retrieved 10 February, 2010, from http://intelligentmeasurement.wordpress.com/?s=SEVEN+POINT+LIKERT+SCALE

Gerbino, P. G., Griffin, E. D., d'Hemecourt, P. A., Kim, T., Kocher, M. S., Zurakowski, D., et al. (2006). Patellofemoral pain syndrome: evaluation of location and intensity of pain. *The Clinical Journal of Pain, 22*(2), 154-159.

Gibbs, N. (1993). Injuries in professional rugby league: a three-year prospective study of the South Sydney Professional Rugby League Football Club. *American Journal of Sports Medicine, 21*(5), 696-700.

Gissane, C., Jennings, D., Kerr, K., & White, J. A. (2002). A pooled data analysis of injury incidence in rugby league football. *Sports Medicine, 32*(3), 211-216.

Goldstein, G., Beer, S., & Hersen, M. (2004). *Comprehensive Handbook of Psychological Assessment Vol 1: Intellectual and Neuropsychological Assessment* New Jersey: John Wiley & Sons.

Gosling, C. R., Gabbe, B. J., & Forbes, A. B. (2008). Triathlon related musculoskeletal injuries: the status of injury prevention knowledge. *Journal of Science and Medicine in Sport, 11*(4), 396-406.

Gray, A. J., & Jenkins, D. G. (2010). Match analysis and the physiological demands of australian football. *Sports Medicine, 40*(4), 347-360.

Grund, T., & Senner, V. (2006). Traction testing of soccer boots under game relevant loading conditions. *The Engineering of Sport 6*, 339-344.

Grund, T., Senner, V., & Grube, K. (2007). Development of a test device for testing soccer boots under gamerelevant highrisk loading conditions. *Sports Engineering, 10*(1), 55-63.

Guten, G. N., & Adner, M. M. (1997). *Running injuries*. Philadelphia: WB Saunders.

Hagen, M., & Hennig, E. (2009). Effects of different shoe-lacing patterns on the biomechanics of running shoes. *Journal of Sports Sciences, 27*(3), 267-275.

Hagen, M., Homme, A., Umlauf, T., & Hennig, E. M. (2010). Effects of different shoe-lacing patterns on dorsal pressure distribution during running and perceived comfort. *Research in Sports Medicine 18*(3), 176-187.

Hagglund, M. (2007). *Epidemiology and prevention of football injuries.* Linköping University Medical Dissertations No.989, Linkoping.

Hagglund, M., Waldén, M., Bahr, R., & Ekstrand, J. (2005). Methods for epidemiological study of injuries to professional football players: developing the UEFA model. *British Journal of Sports Medicine, 39*(6), 340-346.

Hagglund, M., Walden, M., & Ekstrand, J. (2007). Lower reinjury rate with a coach-controlled rehabilitation program in amateur male soccer a randomized controlled trial. *American Journal of Sports Medicine, 35*(9), 1433-1442.

Hagglund, M., Waldén, M., & Ekstrand, J. (2003). Exposure and injury risk in Swedish elite football: a comparison between seasons 1982 and 2001. *Scandinavian Journal of Medicine & Science in Sports, 13*(6), 364-370.

Hagglund, M., Waldén, M., & Ekstrand, J. (2009). Injuries among male and female elite football players. *Scandinavian Journal of Medicine & Science in Sports, 19*(6), 819-827.

Handoll, H. H. G., Gillespie, W. J., Gillespie, L. D., & Madhok, R. (2007). Moving towards evidence-based healthcare for musculoskeletal injuries: featuring the work of the cochrane bone, joint and muscle trauma group. *The Journal of the Royal Society for the Promotion of Health, 127*(4), 168-173.

Hanspal, R. S., Fisher, K., & Nieveen, R. (2003). Prosthetic socket fit comfort score. *Disability & Rehabilitation, 25*(22), 1278-1280.

Hartwig, T. B., Naughton, G., & Searl, J. (2008). Defining the volume and intensity of sport participation in adolescent rugby union players. *International Journal of Sports Physiology & Performance, 3*(1), 94-106.

Hennig, E. M. (2008) Tilte. In & W. Hong & R. Barlett (Vol. Ed.)*. Routledge Handbook of Biomechanics and Human Movement Science* (pp. 231-244). New York.

Holzer, K., & Brukner, P. (2004). Screening of athletes for exercise-induced bronchoconstriction. *Clinical Journal of Sport Medicine, 14*(3), 134-138.

Hong, W. H., Lee, Y. H., Chen, H. C., Pei, Y. C., & Wu, C. Y. (2005). Influence of heel height and shoe insert on comfort perception and biomechanical performance of young female adults during walking. *Foot & Ankle International 26*(12), 1042-1048.

Hoskins, W., Pollard, H., Hough, K., & Tully, C. (2006). Injury in rugby league. *Journal of Science and Medicine in Sport, 9*(1-2), 46-56.

Hreljac, A., Marshall, R. N., & Hume, P. A. (2000). Evaluation of lower extremity overuse injury potential in runners. *Medicine & Science in Sports & Exercise, 32*(9), 1635-1641.

Huguenin, L., Brukner, P., McCrory, P., Smith, P., Wajswelner, H., & Bennell, K. (2005). Effect of dry needling of gluteal muscles on straight leg raise: a randomised, placebo controlled, double blind trial. *British Journal of Sports Medicine, 39*(2), 84-90.

Huson, A. (2000). Biomechanics of the tarsal mechanism: a key to the function of the normal human foot. *Journal of the American Podiatric Medical Association, 90*(1), 12-17.

Impellizzeri, F. M., & Maffiuletti, N. A. (2007). Convergent evidence for construct validity of a 7-Point likert scale of lower limb muscle soreness. *Clinical Journal of Sport Medicine, 17*(6), 494-496.

Impellizzeri, F. M., Rampinini, E., Castagna, C., Martino, F., Fiorini, S., & Wisloff, U. (2008). Effect of plyometric training on sand versus grass on muscle soreness and jumping and sprinting ability in soccer players. *British Journal of Sports Medicine, 42*(1), 42-46.

International Federation of Sports Medicine (2010). Retrieved 20 February, 2010, from http://www.fims.org/

Iwamoto, J., & Takeda, T. (2003). Stress fractures in athletes: review of 196 cases. *Journal of Orthopaedic Science, 8*(3), 273-278.

Johnson, A., Doherty, P. J., & Freemont, A. (2009). Investigation of growth, development, and factors associated with injury in elite schoolboy footballers: prospective study. *British Medical Journal, 338*(1), 490.

Jönhagen, S., Ackermann, P., & Saartok, T. (2009). Forward lunge: a training study of eccentric exercises of the lower limbs. *The Journal of Strength & Conditioning Research, 23*(3), 972-978.

Junge, A., Langevoort, G., Pipe, A., Peytavin, A., Wong, F., Mountjoy, M., et al. (2006). Injuries in team sport tournaments during the 2004 Olympic Games. *The American Journal of Sports Medicine, 34*(4),565-576.

Junge, A., Dvorak, J. & Graf-Baumann, T. (2004). Football injuries during the World Cup 2002. *The American Journal of Sports Medicine, 32*(Suppl 1), 23S-27S.

Junge, A., Cheung, K., Edwards, T., & Dvorak, J. (2004). Injuries in youth amateur soccer and rugby players—comparison of incidence and characteristics. *British Journal of Sports Medicine, 38*(2), 168-172.

Junge, A., Dvorak, J., Chomiak, J., Peterson, L., & Graf-Baumann, T. (2000). Medical history and physical findings in football players of different ages and skill levels. *The American Journal of Sports Medicine, 28*(Suppl 5), 16-21.

Karoly, P., Jensen, M. P., & Goldstein, A. P. (1987). *Multimethod assessment of chronic pain*. Oxford: Pergamon Press

Kaufman, K. R., Brodine, S. K., Shaffer, R. A., Johnson, C. W., & Cullison, T. R. (1999). The effect of foot structure and range of motion on musculoskeletal overuse injuries. *The American Journal of Sports Medicine, 27*(5), 585-593.

Kinchington, M. (2003). *Implications of Foot - Shoe Interactions in Sports Medicine.* Paper presented at the ISB Technical Group on Footwear Biomechanics, 6th Symposuim on Footwear Biomechanics, Queenstown.

Kinchington, M. (2009). *Lower limb injury implications for Taekwondo* Paper presented at the 2nd International Symposium for Taekwonddo Studies Copenhagen, Denmark.

Kinchington, M., Ball, K., & Naughton, G. (2010). Reliability of an instrument to determine lower limb comfort in professional football. *Journal fo Sports Medicine Open Access, 1*, 77-85.

King, D., & Gabbett, T. (2008). Training injuries in New Zealand amateur rugby league players. *Journal of Science and Medicine in Sport, 11*(6), 562-565.

King, D. A., Hume, P. A., Milburn, P. D., & Guttenbeil, D. (2010). Match and training injuries in rugby league: a review of published studies. *Sports Medicine, 40*(2), 163-178.

King, M., Nazareth, I., Lampe, F., Bower, P., Chandler, M., Morou, M., et al. (2005). Impact of participant and physician intervention preferences on randomized trials: a systematic review. *The Journal of the American Medical Association 293*(9), 1089-1099.

Kleindienst, F., Bruggemann, G. P., Krabbe, B., & Walther, M. (2003). *Functional grading of cushioning and forefoot flexibility characteristics in running shoes*

Paper presented at the 6th Symposium on Footwear Biomechanics, Queenstown.

Kolcaba, K., & Steiner, R. (2000). Empirical evidence for the nature of holistic comfort. *Journal of Holistic Nursing, 18*(1), 46-62.

Kolcaba, K. Y. (1992). Holistic comfort: operationalizing the construct as a nurse-sensitive outcome. *Advances in Nursing Science, 15*(1), 1-10.

Kolcaba, K. Y., & Fisher, E. M. (1996). A holistic perspective on comfort care as an advance directive. *Critical Care Nursing Quarterly, 18*(4), 66-76.

Kolcaba, K. Y., & Kolcaba, R. J. (1991). An analysis of the concept of comfort. *Journal of Advanced Nursing, 16*(11), 1301-1310.

Kong, P. W., & Bagdon, M. (2010). Shoe preference based on subjective comfort for walking and running. *Journal of the American Podiatric Medical Association, 100*(6), 456-462.

Krosshaug, T., Andersen, T. E., Olsen, O. E. O., Myklebust, G., & Bahr, R. (2005). Research approaches to describe the mechanisms of injuries in sport: limitations and possibilities. *British Journal of Sports Medicine, 39*(6), 330-339.

Lake, M. J. (2000). Determining the protective function of sports footwear. *Ergonomics, 43*(10), 1610-1621.

Lake, M. J., & Lafortune, M. A. (1998). Mechanical inputs related to perception of lower extremity impact loading severity. *Medicine & Science in Sports & Exercise, 30*(1), 136-143.

Lambson, R. B., Barnhill, B. S., & Higgins, R. W. (1996). Football cleat design and its effect on anterior cruciate ligament injuries. *The American Journal of Sports Medicine, 24*(2), 155-159.

Langberg, H., Ellingsgaard, H., Madsen, T., Jansson, J., Magnusson, S., Aagaard, P., et al. (2007). Eccentric rehabilitation exercise increases peritendinous type I collagen synthesis in humans with Achilles tendinosis. *Scandinavian Journal of Medicine & Science in Sports, 17*(1), 61-66.

Llana, S., Brizuela, G., Dura, J., & Garcia, A. (2002). A study of the discomfort associated with tennis shoes. *Journal of Sports Sciences, 20*(9), 671-679.

Lozano, L. M., García-Cueto, E., & Muñiz, J. (2008). Effect of the number of response categories on the reliability and validity of rating scales.

Methodology: European Journal of Research Methods for the Behavioral and Social Sciences, 4(2), 73-79.

Lüthje, P., Nurmi, I., Kataja, M., Belt, E., Helenius, P., Kaukonen, J., et al. (1996). Epidemiology and traumatology of injuries in elite soccer: a prospective study in Finland. *Scandinavian Journal of Medicine & Science in Sports, 6*(3), 180-185.

Luo, G., Stergiou, P., Worobets, J., Nigg, B., & Stefanyshyn, D. (2009). Improved footwear comfort reduces oxygen consumption during running. *Footwear Science, 1*(1), 25 - 29.

Luthje, P. (1996). Epidemiology and traumatology of injuries in elite soccer: A prospective study in Finland. *Scandinavian Journal of Medicine & Science in Sports, 6*(3), 180-185.

McKay, G., Goldie, P., Payne, W., & Oakes, B. (2001). Ankle injuries in basketball: injury rate and risk factors. *British Journal of Sports Medicine, 35*(2), 103-108.

McManus, A., Stevenson, M., Finch, C., Elliott, B., Hamer, P., Lower, A., et al. (2004). Incidence and risk factors for injury in non-elite Australian Football. *Journal of Science and Medicine in Sport, 7*(3), 384-391.

McNitt, A., Waddington, D., & Middour, R. (1997). Traction measurement on on natural turf. *Safety in American Football: American Society for Testing and Materials*, 145-155.

McPoil, T. G. (2000). Athletic footwear: Design, performance and selection issues. *Journal of Science & Medicine in Sport, 3*(3), 260-267.

Medibank (2006). Safe Sports Report Retrieved 10 February 2010, from http://www.medibank.com.au/pdfs/SafeSportsReport2006.pdf.

Medical-Olympic (2010). Retrieved 20 February, 2010, from http://www.olympic.org/en/content/The-IOC/Commissions/Medical/

Meyers, M. C., & Barnhill, B. S. (2004). Incidence, causes, and severity of high school football injuries on field turf versus natural grass: a 5-year prospective study. *American Journal of Sports Medicine, 32*(7), 1626-1638.

Milburn, P. D., & Barry, E. B. (1998). Shoe-surface interaction and the reduction of injury in rugby union. *Sports Medicine, 25*(5), 319-327.

Miller, A., & Callister, R. (2009). Reliable lower limb musculoskeletal profiling using easily operated, portable equipment. *Physical Therapy in Sport, 10*(1), 30-37.

Miller, J. E., Nigg, B. M., Liu, W., Stefanyshyn, D. J., & Nurse, M. A. (2000). Influence of foot, leg and shoe characteristics on subjective comfort. *Foot & Ankle International, 21*(9), 759-767.

Miller, R. H., & Hamill, J. (2009). Computer simulation of the effects of shoe cushioning on internal and external loading during running impacts. *Computer Methods in Biomechanics and Biomedical Engineering, 12*(4), 481-490.

Mills, K., Blanch, P., & Vicenzino, B. (2010). Identifying clinically meaningful tools for measuring comfort perception of footwear. *Medicine & Science in Sports & Exercise, 42*(10), 1966-1971.

Morio, C., Lake, M. J., Gueguen, N., Rao, G., & Baly, L. (2009). The influence of footwear on foot motion during walking and running. *Journal of Biomechanics, 42*(13), 2081-2088.

Mundermann, A., Nigg, B., Humble, R., & Stefanyshyn, D. (2004). Consistent immediate effects of foot orthoses on comfort and lower extremity kinematics, kinetics, and muscle activity. *Journal of Applied Biomechanics, 20*(1), 71-84.

Mundermann, A., Nigg, B. M., Neil Humble, R., & Stefanyshyn, D. J. (2003a). Foot orthotics affect lower extremity kinematics and kinetics during running. *Clinical Biomechanics, 18*(3), 254-262.

Mundermann, A., Nigg, B. M., Humble, R. N., & Stefanyshyn, D. J. (2003b). Orthotic comfort is related to kinematics, kinetics, and EMG in recreational runners. *Medicine and Science in Sports and Exercise 35*(10), 1710-1719.

Mundermann, A., Nigg, B. M., Stefanyshyn, D. J., & Humble, R. N. (2002). Development of a reliable method to assess footwear comfort during running. *Gait & Posture 16*(1), 38-45.

Mundermann, A., Stefanyshyn, D. J., & Nigg, B. M. (2001). Relationship between footwear comfort of shoe inserts and anthropometric and sensory factors. *Medicine and Science in Sports and Exercise 33*(11), 1939-1945.

Murphy, D. F., Connolly, D. A. J., & Beynnon, B. D. (2003). Risk factors for lower extremity injury: a review of the literature. *British journal of Sports Medicine 37*(1), 13-29.

Neely, F. G. (1998). Intrinsic risk factors for exercise-related lower limb injuries. *Sports Medicine, 26*(4), 253-263.

Nester, C. J., Van Der Linden, M. L., & Bowker, P. (2003). Effect of foot orthoses on the kinematics and kinetics of normal walking gait. *Gait & Posture, 17*(2), 180-187.

Nigg, B., & Wakeling, J. (2001). Impact forces and muscle tuning: a new paradigm. *Exercise and Sport Sciences Reviews, 29*(1), 37-41.

Nigg, B. M. (2001). The role of impact forces and foot pronation: a new paradigm. *Clinical Journal of Sport Medicine, 11*(1), 2-9.

Nigg, B. M., Nurse, M. A., & Stefanyshyn, D. J. (1999). Shoe inserts and orthotics for sport and physical activities. *Medicine & Science in Sports & Exercise, 31*(7), 421- 428.

Nigg, B. M., & Segesser, B. (1992). Biomechanical and orthopedic concepts in sport shoe construction. *Medicine & Science in Sports & Exercise, 24*(5), 595-602.

Norton, K., Schwerdt, S., & Lange, K. (2001). Evidence for the aetiology of injuries in Australian football. *British Journal of Sports Medicine, 35*(6), 418-423.

Nurse, M. A., Hulliger, Wakeling, J. M., Nigg, B. M., & Stefanyshyn, D. J. (2005). Changing the texture of footwear can alter gait patterns. *Journal of Electromyography and Kinesiology, 15*(5), 496-506.

O'Leary, K., Vorpahl, K. A., & Heiderscheit, B. (2008). Effect of cushioned insoles on impact forces during running. *Journal of the American Podiatric Medical Association, 98*(1), 36-41.

Orchard, J. (2002). Is there a relationship between ground and climatic conditions and injuries in football? *Sports Medicine, 32*(7), 419-432.

Orchard, J. (2004). Missed time through injury and injury management at an NRL club. *Sport Health, 22*(1), 11-20.

Orchard, J., & Finch, C. F. (2002). Australia needs to follow New Zealand's lead on sports injuries. *Medical Journal of Australia 177*, 38-39.

Orchard, J., & Seward, H. (2002). Epidemiology of injuries in the Australian Football League, seasons 1997-2000. *British Medical Journal, 36*(1), 39.

Orchard, J., & Seward, H. (2008). Injury report 2008 Australian Football League Retrieved 10 February, 2010, from http://injuryupdate.com.au/images/research/AFL_Injury_Report_2008.pdf

Orchard, J., Seward, H., McGivern, J., & Hood, S. (1999). Rainfall, evaporation and the risk of non-contact anterior cruciate ligament injury in the Australian Football League. *Medical Journal of Australia, 170*(7), 304-306.

Orendurff, M. S., Rohr, E. S., Segal, A. D., Medley, J. W., Green, J. R., & Kadel, N. J. (2008). Regional foot pressure during running, cutting, jumping, and landing. *The American Journal of Sports Medicine, 36*(3), 566-571.

Orlando, A. R., & King, P. M. (2004). Relationship of demographic variables on perception of fatigue and discomfort following prolonged standing under various flooring conditions. *Journal of Occupational Rehabilitation, 14*(1), 63-76.

Pabst, H., Segesser, B., Bulitta, M., Wetzel, D., & Bertram, S. (2001). Efficacy and tolerability of escin/diethylamine salicylate combination gels in patients with blunt injuries of the extremities. *International Journal of Sports Medicine, 22*(6), 430-436.

Peat, J. K., & Barton, B. (2005). *Medical statistics: A guide to data analysis and critical appraisal*. Malden Blackwell.

Rampinini, E., Coutts, A., Castagna, C., Sassi, R., & Impellizzeri, F. (2007). Variation in top level soccer match performance. *International Journal of Sports Medicine, 28*(12), 1018-1024.

Redmond, A. C., Crosbie, J., & Ouvrier, R. A. (2006). Development and validation of a novel rating system for scoring standing foot posture: The foot posture index. *Clinical Biomechanics, 21*(1), 89-98.

Reilly, T., Bangsbo, J., & Franks, A. (2000). Anthropometric and physiological predispositions for elite soccer. *Journal of Sports Sciences, 18*(9), 669-683.

Reilly, T., Drust, B., & Clarke, N. (2008). Muscle fatigue during football match-play. *Sports Medicine, 38*(5), 357-367.

Reinschmidt, C., Van den Bogert, A., Nigg, B., Lundberg, A., & Murphy, N. (1997). Effect of skin movement on the analysis of skeletal knee joint motion during running. *Journal of Biomechanics, 30*(7), 729-732.

Richards, D. P., Ajemian, S. V., Wiley, J. P., Brunet, J. A., & Zernicke, R. F. (2002). Relation between ankle joint dynamics and patellar tendinopathy in elite volleyball players. *Clinical Journal of Sport Medicine, 12*(5), 266-272.

Rösch, D., Hodgson, R., Peterson, L., Graf-Baumann, T., Junge, A., Chomiak, J., et al. (2000). Assessment and evaluation of football performance. *The American Journal of Sports Medicine, 28*(supp 5), 29-39

Saetran, L., & Norstud, H. (2008). Factors influencing on running. *In Sport Aerodynamics CISM Courses and Lectures, 506*, 9-22.

Scase, E., Cook, J., Makdissi, M., Gabbe, B., & Shuck, L. (2006). Teaching landing skills in elite junior Australian football: evaluation of an injury prevention strategy. *British Journal of Sports Medicine, 40*(10), 834-838.

Shorten, M., & Mientjes, M. (2003). *The effects of shoe cushioning on impact force during running.* Paper presented at the ISB Technical Group on Footwear Biomechanics, 6th Symposium on Footwear Biomechanics, Queenstown, New Zealand.

Slater, K. (1985). *Human comfort*. Springfield USA Thomas.

Sports Medicine Australia, Olympic Gold and Australia's Economy Harmed by Injuries, Media Release (2008). Retrieved 10 February, 2010, from http://www.sma.org.au/mediareleases/pdfmediareleases/2008.pdf

Stacoff, A., Reinschmidt, C., Nigg, B. M., Van Den Bogert, A. J., Lundberg, A., Denoth, J., et al. (2001). Effects of shoe sole construction on skeletal motion during running. *Medicine & Science in Sports & Exercise, 33*(2), 311-319.

Stagni, R., Leardini, A., O'Connor, J. J., & Giannini, S. (2003). Role of passive structures in the mobility and stability of the human subtalar joint: a literature review. *Foot & Ankle International, 24*(5), 402-409.

Stefanyshyn, D. J., & Nigg, B. M. (2000). Influence of midsole bending stiffness on joint energy and jump height performance. *Medicine & Science in Sports & Exercise, 32*(2), 471- 476.

Szczepanski, L. (2008). Measuring the effectiveness of strategies and quantifying players' performance in football. *International Journal of Performance Analysis in Sport, 8*(2), 55-66.

Takemura, M., Schneiders, A., Bell, M., & Milburn, P. (2007). Association of ground hardness with injuries in rugby union. *British Journal of Sports Medicine, 41*(9), 582-587.

Taunton, J., Ryan, M., Clement, D., McKenzie, D., Lloyd-Smith, D., & Zumbo, B. (2003). A prospective study of running injuries: the Vancouver Sun Run “in training” clinics. *British Journal of Sports Medicine, 37*(3), 239-244.

Tessitore, A., Meeusen, R., Pagano, R., Benvenuti, C., Tiberi, M., & Capranica, L. (2008). Effectiveness of active versus passive recovery strategies after futsal games. *The Journal of Strength & Conditioning Research, 22*(5), 1402-1412.

Tine, W., Witvrouw, E., De Cock, A., & De Clercq, D. (2005). *Gait related risk factors for exercise related lower leg pain during shod running.* Paper presented at the 7th Symposium on Footwear Biomechanics, Clevland.

Twomey, D., Finch, C., Roediger, E., & Lloyd, D. (2009). Preventing lower limb injuries: is the latest evidence being translated into the football field? *Journal of Science and Medicine in Sport/Sports Medicine Australia, 12*(4), 452-456.

Van Mechelen, W., Hlobil, H., & Kemper, H. (1992). Incidence, severity, aetiology & prevention of sports injuries. a review of concepts. *Sports Medicine 14*(2), 82-99.

Van Middelkoop, M., Kolkman, J., Van Ochten, J., Bierma-Zeinstra, S., & Koes, B. (2008). Prevalence and incidence of lower extremity injuries in male marathon runners. *Scandinavian Journal of Medicine & Science in Sports, 18*(2), 140-144.

Verrall, G., Kalairajah, Y., Slavotinek, J., & Spriggins, A. (2006). Assessment of player performance following return to sport after hamstring muscle strain injury. *Journal of Science and Medicine in Sport, 9*(1-2), 87-90.

Villwock, M. R., Meyer, E. G., Powell, J. W., Fouty, A. J., & Haut, R. C. (2009). Football playing surface and shoe design affect rotational traction. *The American Journal of Sports Medicine, 37*(3), 518-525.

Von Guenthner, S., & Hammermeister, J. (2007). Exploring relations of wellness and athletic coping skills of collegiate athletes: implications for sport performance. *Psychological Reports, 101*(3), 1043-1049.

Wakeling, J. M., Pascual, S. A., & Nigg, B. M. (2002). Altering muscle activity in the lower extremities by running with different shoes. *Medicine & Science in Sports & Exercise, 34*(9), 1529-1532.

Walden, M., Hägglund, M., & Ekstrand, J. (2005). UEFA Champions League study: a prospective study of injuries in professional football during the 2001–2002 season. *British Journal of Sports Medicine, 39*(8), 542-546.

Walden, M., Hägglund, M., & Ekstrand, J. (2007). Football injuries during European championships 2004–2005. *Knee Surgery, Sports Traumatology, Arthroscopy, 15*(9), 1155-1162.

Wegener, C., Burns, J., & Penkala, S. (2008). Effect of neutral-cushioned running shoes on plantar pressure loading and comfort in athletes with cavus feet: a crossover randomized controlled trial. *American Journal of Sports Medicine, 36*(11), 2139-2146.

Williams, A., & Nester, C. (2006). Patient perceptions of stock footwear design features. *Prosthetics and orthotics international, 30*(1), 61-71.

Williams, D. S., McClay, I. S., & Hamill, J. (2001). Arch structure and injury patterns in runners. *Clinical Biomechanics, 16*(4), 341-347.

Williamson, A., & Hoggart, B. (2005). Pain: a review of three commonly used pain rating scales. *Journal of Clinical Nursing, 14*(7), 798-804.

Witana, C. P., Goonetilleke, R. S., Xiong, S., & Au, E. Y. (2009). Effects of surface characteristics on the plantar shape of feet and subjects' perceived sensations. *Applied Ergonomics, 40*(2), 267-279.

Wong, P., & Hong, Y. (2005). Soccer injury in the lower extremities. *British Journal of Sports Medicine, 39*(8), 473-482.

Yeung, E., & Yeung, S. (2003). Interventions for preventing lower limb soft-tissue injuries in runners (Cochrane Review). *The Cochrane Library, 1*.

Young, W. B., & Pryor, L. (2007). Relationship between pre-season anthropometric and fitness measures and indicators of playing performance in elite junior Australian Rules football. *Journal of Science and Medicine in Sport, 10*(2), 110-118.

Yung-Hui, L., & Wei-Hsien, H. (2005). Effects of shoe inserts and heel height on foot pressure, impact force, and perceived comfort during walking. *Applied Ergonomics, 36*(3), 355-362.

Zadpoor, A. A., & Nikooyan, A. A. (2010). Modeling muscle activity to study the effects of footwear on the impact forces and vibrations of the human body during running. *Journal of Biomechanics, 43*(2), 186-193.

Zifchock, R., & Davis, I. (2008). A comparison of semi-custom and custom foot orthotic devices in high-and low-arched individuals during walking. *Clinical Biomechanics, 23*(10), 1287-1293.

Zou, K. H., Tuncali, K., & Silverman, S. G. (2003). Correlation and Simple Linear Regression1. *Radiology, 227*(3), 617-628.

APPENDIX A:

Research Consent Letters From Participating Football Organisations

---

new south wales RUGBY

NSW Rugby Union Ltd
ABN 70 000 222 711

Locked Bag 1222
Paddington NSW 2021

Gold Members Carpark
Aussie Stadium
Driver Avenue
Moore Park NSW 2021

T 02 8354 3300
F 02 8354 3399
enquiries@nswrugby.com.au
www.nswrugby.com.au

7 February 2007

Dear Chairperson of the Human Ethics Committee at Victoria University

The NSW Waratahs endorses the research proposal of Michael Kinchington (PhD candidate). Our organisation will ensure support for the research to be conducted via facilitating access to players, training and playing facilities.

We welcome the opportunity to apply the research to potentially advance the performance of our players, assist with injury prevention and generally aid the well being of the players.

We will be encouraging players to participate in the research, as the overall experience will be of substantial benefit. However we respect the need for participation to be strictly voluntary, and players who do not wish to be involved will not be penalised.

Yours Sincerely

[redacted]

Tony D'Arcy
Waratah High Performance General Manager

WARATAHS | HSBC The world's local bank

CELEBRATING OUR 100TH SEASON

14 February 2007

The Chairperson
Human Ethics Committee
Victoria University,

Dear Chairperson,

The Sydney Rosters Rugby League Club endorses the research proposal of Michael Kinchington (PhD candidate).

Our Club will ensure support for the research to be conducted via facilitating access to players, training and playing facilities.

We welcome the opportunity to apply the research to potentially advance the performance of our players, assist with injury prevention and generally aid the well being of the players.

We will actively encourage players to participate in the research, as the overall experience will be of substantial benefit. However we respect the need for participation to be strictly voluntary, and players who do not wish to be involved will not be penalised.

Yours sincerely

[redacted]

Brian Canavan
Chief executive Officer

Sydney Roosters | (PO Box 1532) 93-97 Spring St, Bondi Junction NSW 2022 | Ph: (02) 9386 3210 | Administration Fax: (02) 9387 8554 : Marketing Fax: (02) 9369 4766
Email: receptionfootball@eastleaguesclub.com.au | www.sydneyroosters.com.au | Eastern Suburbs District Rugby League Football Club Ltd | ABN 74 522 909 012

SYDNEY SWANS

Dear Chairperson of the Human Ethics Committee at Victoria University

The Sydney Swans endorses the research proposal of Michael Kinchington (PhD candidate). Our organisation will ensure support for the research to be conducted via facilitating access to players, training and playing facilities.
We welcome the opportunity to apply the research to potentially advance the performance of our players, assist with injury prevention and generally aid the well being of the players.

We will be encouraging players to participate in the research, as the overall experience will be of substantial benefit. However we respect the need for participation to be strictly voluntary, and players who do not wish to be involved will not be penalised.

Yours Sincerely

[redacted]

MATT CAMERON
PHYSIOTHERAPIST
REHABILITATION CO-ORDINATOR
SYDNEY SWANS FOOTBALL CLUB

Sydney Swans Limited A.C.N. 063 349 708 sydneyswans.com.au
SCG Light Tower 4, Driver Avenue Moore Park NSW 2021 P.O. Box 173, Paddington NSW 2021
Phone 02 9339 9123 | **Marketing Fax** 02 9339 9100 | **Football Fax** 02 9339 9101

Founded 1874
Premiers 1881 1885 1888 1889 1890 1909 1918 1933 2005

QBE

RABBITOHS Est.1908

South Sydney District Rugby League Football Club Limited ABN. 28 002 487 390

1 September 2006

Dear Chairperson of the Human Ethics Committee at Victoria University

The South Sydney Rugby Football Club endorses the research proposal of Michael Kinchington (PhD candidate). Our organisation will ensure support for the research to be conducted via facilitating access to players, training and playing facilities. We welcome the opportunity to apply the research to potentially advance the performance of our players, assist with injury prevention and generally aid the well being of the players.

We will be encouraging players to participate in the research, as the overall experience will be of substantial benefit. However we respect the need for participation to be strictly voluntary, and players who do not wish to be involved will not be penalised.

Yours Sincerely

David Boyle
Strength & Conditioning Coordinator

Telephone Direct: 02 8306 9920 | F: 8306 9911 | W: www.souths.com.au

RABBITOHS

2007 celebrates 100 SEASONS

Our Community SOUTHS CARES

APPENDIX B:

Participant Information Sheet

VICTORIA UNIVERSITY | A NEW SCHOOL OF THOUGHT

School of Human Movement,

CONSENT FORM FOR PARTICIPANTS INVOLVED IN RESEARCH

INFORMATION TO PARTICIPANTS

We would like to invite you to be a part of a study into:

An investigation into associations between lower extremity comfort, injury and performance in elite footballers

Dear Research Participant,

Michael Kinchington (principal investigator) is conducting a study to aid the understanding of the role between lower limb injury, comfort and footwear in sport. The primary winter football codes in Australia (AFL, NRL, Rugby Union) will be the subject of investigation. From the findings of this study we hope to develop guidelines to reduce the risk of injury and maximise performance.

i. Introduction

Currently a void in leg comfort research and the effect of footwear exists. Lower limb comfort is innately an individual perception, however is important for running based activities. Because football codes have high running demands, a hypothesis of the research is that lower limb discomfort is a determinant of lower limb injury. As a participant in the research, two areas which are important to football performance will be examined; the role of leg-foot comfort and footwear usage patterns. A component of the research project includes investigating lower limb comfort and influences of footwear relative to injury. A diverse population group will be studied including professional football codes. Your participation will assist develop guidelines for professional and amateur football codes in the effort to reduce lower limb injury.

ii. About the researcher/s

Michael Kinchington is a qualified Podiatrist who has a clinical and research interest in footwear, injury and lower limb biomechanics. Michael Kinchington is enrolled as a PhD candidate at Victoria University and is the principal investigator of the research project. Other persons involved in the project are Dr Kevin Ball (Principal Supervisor) of Victoria University, Melbourne and Professor Geraldine Naughton (Associate Supervisor) of Australian Catholic University, Melbourne.

iii. Use of information and participant rights

Results obtained in this study and information obtained will be made available to the club at all times. However, no findings which could identify participants specifically will be published or released in the public domain. The combined results of all participants may be presented at scientific conferences or published in a peer-reviewed journal; however they will not identify individuals. All personal information will be de-identified, by use of a code number, to ensure records remain anonymous. Only the investigators named and nominees of the participating clubs will have access to the coded data which will be stored in a secure manner as prescribed by university regulations.

iv. Benefits

This research program offers benefits to participating individuals and organisations, the medical and general community. It is hoped that this study will further the understanding of lower limb comfort, footwear and performance. This in turn may significantly assist the participating organisations understanding of lower limb injury and management of individuals in relation to footwear requirements and identifying injury risk factors.

v. Risks

The data collection will involve no physical duress for subjects who volunteer to participate in the research. There are no potential physical risks to the subjects. All data collected will be coded to ensure anonymity.

vi. Procedures

Research participants will be required to cooperate for the following procedures:

i. Weekly lower limb comfort will be gauged using an index developed for the research.
ii. Footwear brand, style and type will be recorded at one main training session and match day.

vii. Conclusion

The advancement of medically related research is dependent on the generosity of individuals in donating their time. It is hoped that this study will further our understanding of aspects pertinent to football. I thank you for your participation in the research program. Should you require any further clarification please do not hesitate to contact the principal investigator: Mr Michael Kinchington mobile: XXXXXXXXX.

PARTICIPANT CONSENT FORM

Advancing the understanding of lower limb comfort and the role of footwear in professional sport.

You are making a decision whether or not to participate. Your signature indicates that, having read the Participant Information Statement, you have decided to take part in the study. The rights of any Individuals who decline to be involved in the research will be respected.

....	....
Signature of Research Participant	Signature of Witness

………………………………………………… ………………………………………

(Please PRINT name) (Please PRINT name)

……………………………………………… ………………………………………

Date Nature of Witness

…………………………………………………

Signature of Investigator

If you have any queries or complaints about the way you have been treated, you may contact the Secretary, Victoria University Human Research Ethics Committee, Victoria University, PO Box 14428, Melbourne, VIC, 8001 phone (03) 9919 4781

APPENDIX C:

Confirmation of manuscripts for publication

Chapter 3. Development of a Novel Rating System to Assess Lower Extremity Comfort

27th April 2010

Dear Mr. Kinchington,

Your manuscript, "Development of a novel rating system to assess lower limb comfort," has been accepted for publication in the **Journal of the American Podiatric Medical Association**. You will be notified of the issue in which your paper will appear.

Very sincerely,
Warren Joseph
Editor

From: **japma@allentrack.net**

Sent: Friday, 25 March 2011 6:47:20 AM

To: michael.kinchington@live.vu.edu.au

Dear Mr. Kinchington,

Your paper entitled, "Development of a novel rating system to assess lower limb comfort" has been scheduled for publication in our July/August 2011 issue, due out in mid-July.
We expect to have the edited manuscript ready for your review the first week in May.
At this time, you will have the opportunity to review the edited manuscript, answer queries, and make text changes.

Sincerely,
Noelle A. Boughanmi, MS
Managing Editor, JAPMA

Chapter 4. Reliability of An Instrument To Determine Lower Limb Comfort in Professional Football

22 April 2010

Dear Mr Kinchington

Congratulations on having your paper "Reliability of an instrument to determine lower limb comfort in professional football" accepted for **Open Access Journal of Sports Medicine.**

As previously mentioned by my colleague, Madeline Lloyd, I will supervise your paper through the typesetting process. You will receive an email with your proofs to check and approve within the next four weeks. At this stage publication has been scheduled for May 2010.

If you have any questions about this publishing process please do let me know.

Best regards

Mr Fogarty
Dove Medical Press
2G, 5 Ceres Court, Mairangi Bay, Auckland, New Zealand
PO Box 300-008, Albany, Auckland, 0752, New Zealand
Phone: +649 476 6466
Fax: +649 476 6469

JOURNAL OF SPORTS SCIENCE & MEDICINE
ELECTRONIC JOURNAL (ISSN 1303-2968)
http://www.jssm.org

EDITORIAL OFFICE
Hakan Gür, MD, PhD, Journal of Sports Science and Medicine,
Department of Sports Medicine, Medical Faculty of Uludag University, 16059 Bursa, Turkey
Phone: +90 (532) 326 82 26 Fax: +90 (224) 442 87 27 E-mail: hakan@uludag.edu.tr

October 11, 2010

Michael Kinchington
Victoria University School of Human Movement,
Recreation & Performance
Australia

Manuscript: #1687-2010/JSSM

TITLE: "Monitoring of lower limb comfort and injury in elite football"

Dear Dr. Kinchington,

I am glad to inform you that your revised manuscript is accepted for publication in the Journal of Sports Science and Medicine and it will be published in December 2010 issue of JSSM. The manuscript will now be edited for style and format.

Please do not hesitate to contact me if you have any questions.

Thank you for giving the JSSM the opportunity to publish your work

Yours Sincerely

Hakan Gur, MD, PhD
Editor-in-Chief

Chapter 6. Effects Of Footwear On Comfort and Injury In Professional Football

To michael.kinchington@live.vu.edu.au

From: **onbehalfof+e.m.winter+shu.ac.uk@manuscriptcentral.com** on behalf of **e.m.winter@shu.ac.uk**

Sent: Sunday 29th May 2010 8:10:54 PM

To: michael.kinchington@live.vu.edu.au

29-May-2011

Dear Mr KINCHINGTON:

It is a pleasure to accept your manuscript entitled "Effects of footwear on comfort and injury in professional football (Rugby League)" in its current form for publication in the Journal of Sports Sciences.

Thank you for your fine contribution. On behalf of the Editors of the Journal of Sports Sciences, we look forward to your continued contributions to the Journal.

Sincerely,
Prof. Alan Nevill
Editor in Chief, Journal of Sports Sciences
a.m.nevill@wlv.ac.uk

Chapter 7. An Investigation Into The Role Of A Footwear Intervention Program For Professional Footballers An Intra-Club Control and Intervention Study

5th January 2011

Dear DR. KINCHINGTON M.,

I am pleased to inform you that your paper entitled:

AN INVESTIGATION INTO THE ROLE OF A FOOTWEAR INTERVENTION PROGRAM FOR PROFESSIONAL FOOTBALLERS. AN INTRA-CLUB CONTROL AND INTERVENTION STUDY

submitted to **J. SPORTS MEDICINE PHYS.FITN.** and registered with the number 3329 has been examined anonymously by the referees has been accepted. I recommend the manuscripts publication in **GAZZETTA MEDICA ITALIANA**, given the contents of the paper.

I therefore await your confirmation of the above so that we can move to the proof stage. If you agree you should confirm it by email and send us the new copyright transfer form signed by all the authors. In the covering letter you should kindly quote the journal which your paper was originally submitted to.

I congratulate you and your co-authors and send you my very best regards.

Managing Editor

Prof. Alberto Oliaro

Chapter 8. Relation Between Lower Limb Comfort and Performance In Elite Footballers

From: **ees.yptsp.0.eea72.ab4f7f7d@eesmail.elsevier.com** on behalf of **Physical Therapy in Sport** (ptis@elsevier.com)

Sent: Wednesday, 2 February 2011 8:47:06 PM

To: michael.kinchington@live.vu.edu.au

Cc: z.hudson@qmul.ac.uk

Ms. Ref. No.: PTIS-1056R1
Title: Relation between lower limb comfort and performance in elite footballers

Dear Mr Michael Kinchington,

I am pleased to confirm that your paper "Relation between lower limb comfort and performance in elite footballers" has been accepted for publication in Physical Therapy in Sport.
Comments from the Editor can be found below. Thank you for submitting your work to this journal.

With kind regards,

Jacqueline Turner
Journal Manager
Physical Therapy in Sport

Comments from the Editor:

Dear Mr Michael Kinchington

Thank you for responding to the reviewer comments and amending the manuscript accordingly. I am pleased to inform you that this has now been accepted for publication and will be sent for typesetting. You will be asked to check the proof and answer any queries raised by the typesetters prior to final publication. Thank you for choosing Physical Therapy in Sport for publication of your manuscript.
Kind regards

Zoe Hudson
Editor
Physical Therapy in Sport