Development and application of holistic injury prevention strategies in pre-elite sport: Implementation in Australian netball

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For Rachel Mary & Claudia Anne

Abstract

This thesis by publication is entitled ‘Development and application of holistic injury prevention strategies in pre-elite sport: Implementation in Australian netball’. Pre-elite athletes sustain high rates of injury at a critical point in their careers. Translating Research into Injury Prevention Practice (TRIPP) is a well-established framework for injury prevention. It consists of six stages and has provided the foundation for this investigation into injury prevention in pre-elite athletes as it has been promoted as an approach that leads to quantifiable real-world injury prevention outcomes. To assess the usefulness of this framework in pre-elite athletes, due to the time constraints of a PhD, netball was used as an exemplar sport.

This thesis comprises five studies, of which four have been published, with one currently under review and being considered for publication. The first study applies TRIPP Stages 1 and 2 by conducting an injury surveillance study and establishing the aetiology and mechanisms of injury at the 2018 17/U & 19/U Australian National Netball Championships (ANNC). This study found an injury incidence rate of 89.4 injuries per 1000 player hours, with ankle sprains being the highest medical attention and sports incapacity injury. Foot blisters and lower back pain were also frequent medical attention injuries, while anterior cruciate ligament (ACL) rupture and sport-related concussion were the next most frequent sports incapacity injuries.

TRIPP Stage 3 is focused on developing injury prevention strategies and the first step is to obtain research evidence. Therefore, our second study was a systematic review investigating injury prevention strategies specific to pre-elite athletes competing in Olympic and professional sports. Eleven studies were identified demonstrating limited evidence supporting exercise and psychology interventions and no evidence supporting the use of equipment or nutrition strategies for preventing injury. This work established that there is a need for high-quality methodologically rigorous research studies to evaluate the efficacy of injury prevention interventions for pre-elite athletes.

The third study, demonstrating TRIPP Stage 4, consists of a randomised controlled trial to assess the effect of ankle tape and taping procedures on proprioception. Netball Australia has an ankle taping

policy whereby pre-elite netball athletes are encouraged to prophylactically tape their ankles, but there is a lack of scientific evidence supporting this policy. This study demonstrated that proprioception improves and is maintained during a netball session with either Sport and Exercise Physiotherapist (SEP) applied or self-applied ankle taping.

TRIPP Stage 5 encourages implementation planning to optimise injury prevention strategy effectiveness. Netball Australia introduced the KNEE (Knee injury prevention for Netballers to Enhance performance and Extend play) program to reduce lower limb injuries. Ankle and knee injuries were the injuries with the highest burden at the 2018 17/U & 19/U ANNC. Therefore, our fourth study investigated how the implementation of the KNEE program could be improved by using concept mapping to identify barriers to its implementation. The coaches, strength and conditioning coaches and physiotherapists working with the 17/U & 19/U State teams identified 'athlete engagement', 'supervision & correction of technique', 'time constraints', 'athlete technique', 'education' and 'support staff resourcing' as the most important and difficult challenges to implementing the KNEE program in pre-elite netball.

The fifth study fulfils TRIPP Stage 6 by assessing the effectiveness of a foot blister prevention strategy at the 2019 17/U & 19/U ANNC. Foot blisters should be easily prevented with correct footwear and hygiene but were one of the most prevalent injuries at the 2018 17/U & 19/U ANNC. The strategy employed in 2019 consisted of every athlete receiving an advice sheet and blister prevention pack (Appendix 17) six weeks prior to the ANNC commencing. A no new shoe less than four weeks before the 2019 ANNC policy was also introduced. Injury surveillance was repeated in 2019, identifying an incidence rate of 82.5 medical attention injuries/1000 player competition hours. Ankle sprains, lower back pain and foot blisters continued to be the most frequently reported medical attention injuries. There was no change in foot blister frequency from 2018 to 2019.

This thesis has identified that the TRIPP framework is useful in guiding essential steps for injury prevention but difficult to apply in the way it was intended in the 'real world'. We identified that ankle sprains, lower back pain and foot blisters were the most prevalent injuries at the 2018 & 2019 17/U & 19/U ANNC, and that ACL rupture and sports-related concussion resulted in the greatest sports

incapacity. Netball Australia had already implemented injury prevention strategies for ankle sprains and ACL rupture. Therefore, the TRIPP Stages should be used as a guide for continual improvement to add value rather than applying the TRIPP model sequentially as it was originally intended, particularly with sports with established prevention programs.

Acknowledgements

This PhD has certainly been a journey. I became passionate about improving development athlete health while working in high performance sport as a physiotherapist and managing elite athletes' injuries that stemmed from their developmental years. Over the past four years I have developed skills I can use to help sporting organisations improve the health of their development athletes.

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List of Abbreviations

UC	University of Canberra
AIS	Australian Institute of Sport
FTEM	Foundations, Talent, Elite and Mastery
OSTRC-H	Oslo Sports Trauma Research Centre
HPQ	Health Problems Questionnaire
IOC	International Olympic Committee
STROBE	Strengthening the Reporting of Observational Studies in Epidemiology
IDP	Intervention Development Process
ANNC	Australian National Netball Championships
ACL	Anterior Cruciate Ligament
CONSORT	Consolidated Standards of Reporting Trials
RE-AIM	Reach, Effectiveness, Adoption, Implementation and Maintenance
IM	Intervention Mapping
SSM	Sports Setting Matrix
ANNC	Australian National Netball Championships
RR	Relative Risk
IRR	Incidence Rate Ratio
ACWR	Acute:Chronic Workload Ratio
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
IDCF	Injury Definitions Concept Framework
CERT	Consensus on Exercise Reporting Template
OCEBM	Oxford Centre for Evidence Based Medicine
CNS	Central Nervous System
SEP	Sport & Exercise Physiotherapist
KNEE	Knee injury prevention for Netballers and Enhance performance and Extend play
CM	Concept Mapping
AMEDA	Active Movement Extent Discrimination Apparatus
NCAA	National Collegiate Athletic Association
NSO	National Sporting Organisation
SSO	State Sporting Organisation
OSICS	Orchard Sports Injury Classification System
KTS	Knowledge Transfer Scheme
TIP	Team-sport Injury Prevention
AMS	Athlete Management System
RED-S	Relative Energy Deficiency in Sport
ACC	Accident Compensation Corporation
PROSPERO	International Prospective Register of Systematic Reviews

Publications and Presentations

Papers published

I hereby certify that this thesis comprises five papers of which I am lead author. I have included as a part of the thesis a written statement from each co-author pertaining to my contribution to the joint publications.

1) **Smyth E**, Piromalli L, Antcliff A, et al. A prospective study of health problems at the 2018 17/U and 19/U Australian National Netball Championships with comparison of surveillance methodology. *J Sci Med Sport*. 2020;23:215-21.
2) **Smyth E**, Newman P, Waddington G, et al. Injury prevention strategies specific to pre-elite athletes competing in Olympic and professional sports – a systematic review. *J Sci Med Sport*. 2019;22:887-901.
3) **Smyth E**, Waddington G, Witchalls J, et al. Does ankle tape improve proprioception acuity immediately after application and following a netball session? A randomised controlled trial. *Phys Ther Sport*. 2021; 48:20-25.
4) **Smyth E**, Appaneal R, Drew M, et al. Identifying the challenges to implementing a neuromuscular warm-up in pre-elite netball. *Int J Sports Sci Coach*. 2021;16:913-24.

Papers submitted for publication

1) **Smyth E**, Toohey L, Antcliff A, et al. Injury surveillance at the 17/U & 19/U Australian National Netball Championships and the effect of a foot blister prevention intervention. *Transl Sports Med*.

Conference presentations

1) **Smyth E**, Piromalli L, Antcliff A et al. A prospective study of injury epidemiology at the 2018 17/U and 19/U Australian National Netball Championships. Paper presented at: Sports Medicine Australia Conference; 2019; Sunshine Coast, QLD, Australia.

2) **Smyth E**, Appaneal R, Drew M et al. Identifying the challenges to implementing a netball neuromuscular warm-up using concept mapping. Paper prepared for: IOC world conference on Prevention of Injury & Illness in Sport; 2020; Monaco. [Postponed due to COVID]
3) **Smyth E,** Waddington G, Toohey L et al. Injury surveillance at the 2019 17/U & 19/U Australian Netball National Championships and the effect of a foot blister prevention intervention. Paper prepared for: IOC World Conference on Prevention of Injury & Illness in Sport; 2020; Monaco. [Postponed due to COVID]
4) **Smyth E**, Appaneal R, Drew M et al. Using concept mapping to improve implementation of Netball Australia's 'KNEE' program. Paper prepared for: Australian Physiotherapy Association Conference; 2021; Brisbane, QLD, Australia. [Postponed due to COVID]
5) **Smyth E**, Waddington G, Witchalls J, et al. Can ankle proprioception be improved by tape? Paper prepared for: Australian Physiotherapy Association Conference; 2021; Brisbane, QLD, Australia. [Postponed due to COVID]

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Chapter 1 Introduction

Background

Sport plays an important role in the lives of Australians. More than 90% of Australian adults express some interest in sport, with 14 million Australians participating in sport each year.[1,2] High-performance sport has become increasingly competitive; with countries investing hundreds of millions of dollars in elite programs.[2] Some Australian sports, however, struggle to stay competitive and rely heavily on government funding to stay afloat. With limited resources, it is more important than ever that the available money is used wisely.[2] Injury has been shown to cause 17% of Australian track and field athletes to retire before age 18,[3] more research is required to establish attrition rates across other sports.

Athletic development is multifactorial and integrative, dependent on physical growth, biological maturation, skill development and behavioural development.[4] The Foundations, Talent, Elite and Mastery (FTEM) model is a guiding framework for athletic development (Figure 1),[5] recognised by the International Olympic Committee (IOC)[4] and utilised extensively within Australia and internationally. It provides a visualisation of the three major stages of athlete development – Foundational, Talent and Elite/Mastery. It establishes a continuum between participation and sports mastery with ten development phases, which allows for greater understanding of athlete development and progression. The 'Talent' stage starts with T1, marking the beginning of the high-performance pathway. This development phase involves an athlete demonstrating their potential through formal and informal talent identification processes. The next level (T2) requires the athlete's talent to be confirmed by immersing them in realistic training and competition contexts. T3 and T4 are collectively known as the pre-elite stage, defined by the FTEM framework as Talent: Practising and Achieving (T3) and Talent: Breakthrough and Reward (T4).[5] The T3 phase contains the largest cohort of potential elite athletes, as athletes can remain at this level from 1–8 years or longer.[5] However these athletes can be vulnerable to injury and illness because of a lack of support at this stage of development.[5] An important part of success is the avoidance of injury and illness as the athlete develops,[6] yet the pre-elite population has been shown to be at high risk of injury[3,7,8] compared to athletes at other FTEM levels.[9] The increased risk of

injury at this stage of development can potentially result in a 'bottleneck' for development because of dropout[3] and an increased prevalence of subsequent injuries,[10,11] hence limiting Australia's talent pool.[12,13] To date, there has been limited research focused on the pre-elite population.

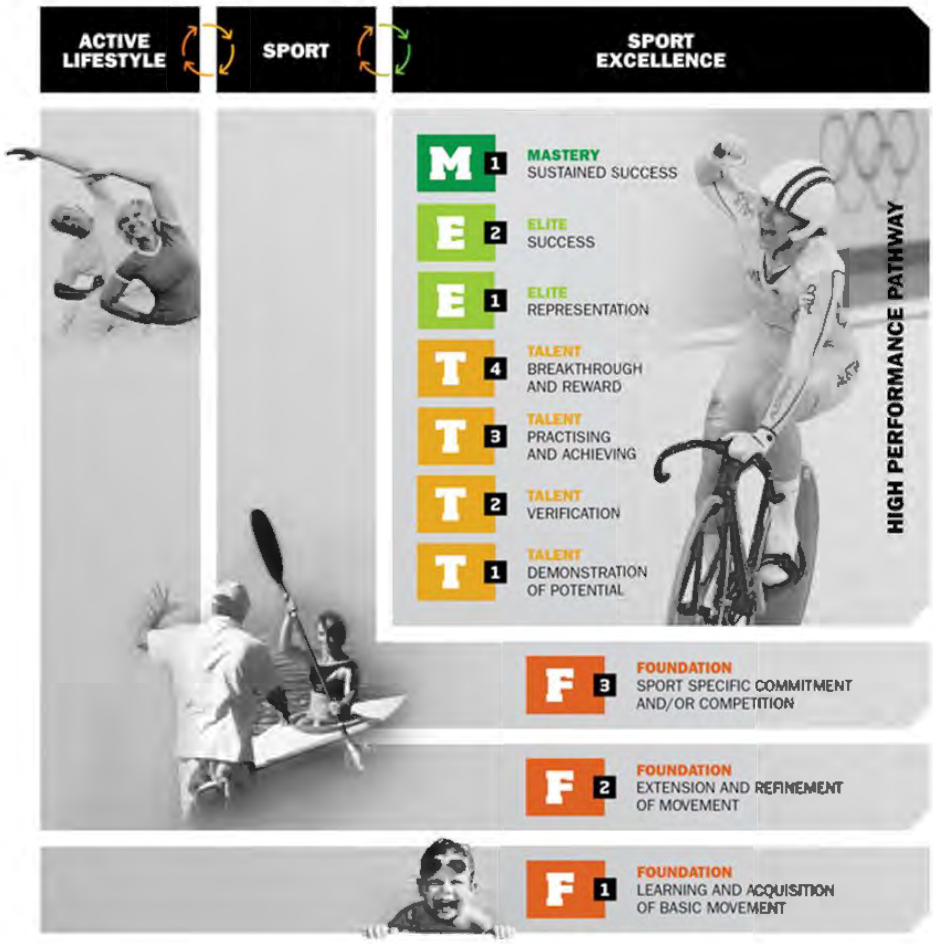

Figure 1: The integrated FTEM (Foundations, Talent, Elite, Mastery) framework. Image courtesy of the Australian Sports Commission, http://www.ausport.gov.au

Injuries in pre-elite athletes

Age and FTEM level align in many sports; however, FTEM level is not defined by an age group, with many, but not all pre-elite athletes in their adolescent years. The IOC has released a consensus statement on youth athletic development outlining some of the challenges faced by adolescent athletes. These challenges include a rapid increase in training load, insufficient rest and recovery, growth and a lack of support services compared to elite athletes.[4,14,15] The IOC consensus statement clearly states that 'no youth athlete should compete-or train or practice in a way that loads the affected injured area, interfering

with or delaying recovery-when in pain or not completely rehabilitated and recovered from an illness or injury'.[4] A number of recent studies have reported high injury rates in pre-elite athletes.[3,9,16-19]

A prospective controlled cohort study investigated injury rates for semi-professional football leagues during the German 2015–16 season.[9] Data were collected by means of a self-administered questionnaire and a mid-season injury report provided by medical staff. Results showed that elite junior (i.e., pre-elite) footballers had the highest incidence rate of overuse injuries (7.4/1000hrs) compared to the highest division of semi-professional football (5.4/1000hrs; RR 1.37, 95%CI 0.95-1.98; p=0.04).

Pre-elite injury rates were also assessed at 15 national sports high schools in Sweden using a prospective cohort study.[17] '*By definition, all adolescent athletes studying at National High Sports Schools are elite athletes. To attend these schools, athletes need to be among the top in terms of ranking in their age group for respective sporting events, on national level'.*[17] A weekly self-reported questionnaire (Oslo Sports Trauma Research Centre (OSTRC) Health Problems Questionnaire (HPQ)[20] and additional questions developed by Jacobsson et al.[21]) was used to collect injury data across 52 weeks from 284 elite adolescent athletes competing in athletics, cross-country skiing, downhill skiing, freestyle skiing, handball, orienteering or ski orienteering. The injury incidence rate was higher during competition (23.8/1000hrs) than during training (2.8/1000hrs) and, on average, 3 of 10 (30.8%) elite adolescent athletes reported being injured every week.

A Norwegian study also used the weekly self-reported HPQ[20] to collect injury data on 260 youth elite athletes (15–16 years of age) across 30 sports for 26 weeks.[16] An average of 43% youth elite athletes had some form of health problem and 25% had substantial health problems during this 26 week period. Substantial health problems were defined as those leading to moderate or severe reduction in training volume or performance, or complete time loss from sport.

In a study in Australian track and field, 103 youth elite athletes were asked to recall over a one to six year period, the type, site and severity of injury sustained when aged 13–17.[3] Eighty-one athletes (78.6%) sustained a cumulative 200 injuries with 74% of these athletes injured more than once. Fourteen athletes (17% of injured athletes) reported retirement due to injury before reaching 18 years of age.

Young elite athletes (n=119) from the National Football Training and Development Centre for Females in France were prospectively observed over an eight-year period.[18] The overall rate of injury was 6.4 per 1000 hours exposure. There aren't any published injury rates for female professional footballers in France to compare to but in the USA, an injury incidence rate of 1.93 injuries per 1000 exposure hours has been reported in women's professional football.[22] Which is at least three times higher than the French young elite athletes.

The injury data of 166 male pre-elite athletes attending the Middle Eastern Youth Sports Academy were prospectively collected over a five-year (2009–14) period.[19] The athletes competed in athletics, squash, table tennis, fencing, gymnastics, swimming, golf and shooting. An injury was defined as any physical complaint requiring medical attention. The overall injury incidence rate was 5.5/1000 hours of exposure, with the prevalence of overuse injuries being 50.3%.

As outlined by the IOC consensus statement on youth athletic development, adolescent athletes are a unique population and, as demonstrated,[3,9,16-19] have a high incidence rate of injuries when compared to senior professional athletes.[9,22] Injuries are a very influential factor that can limit the sustainability of a sport's talent and performance pathway and, in turn, future high-performance success.[23] There is an urgent need to develop a holistic strategy for reducing injuries in pre-elite athletes, with some sports taking formal steps to accomplish this. For example, in 2018 Netball Australia sought assistance from the Australian Institute of Sport (AIS) to help develop aspects of its pre-elite injury prevention strategies.

The sport of netball

Netball is a ball sport played in 77 countries, predominantly in the British Commonwealth.[24] It was initially developed as a game played by females, but it is now played by boys and girls, women and men. Nevertheless, only females play netball professionally and represent their countries at the Commonwealth Games. It is a game in which two teams of seven players oppose each other on a rectangular court 30.5m (100 feet) x 15.25m (50 feet) (Figure 2).[25] The court is divided into thirds and there are goal circles at each end and a centre circle in the middle of the court. Players, according to their designated position, have specified areas in which they can move.

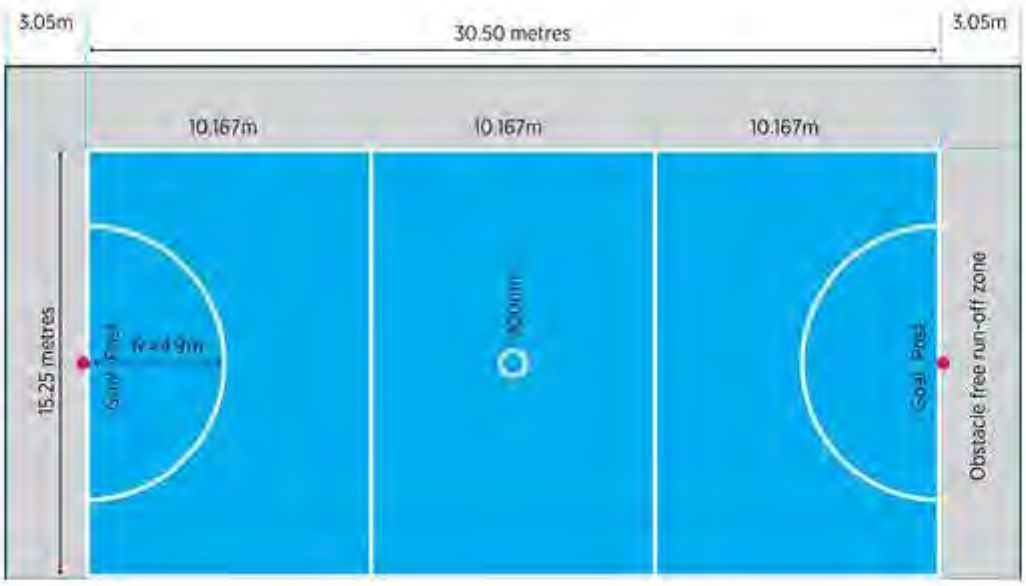

Figure 2: Netball court dimensions

The aim of the game is to move the ball down the court into the goal circle, from where a goal can be scored by shooting the ball into the goal. Players are not permitted to take a step when they are in possession of the ball and they have three seconds to dispose of the ball. Opposition players must remain three feet (0.9m) away from the player in possession of the ball and contact between opposing players is not permitted (although it frequently occurs). Netball is a fast and skilful game requiring running, change of direction, rapid deceleration and acceleration, jumping, throwing, catching and shooting.[26,27]

Injury prevention

Importance of injury prevention in pre-elite athletes

Athlete welfare

Injury prevention needs to be prioritised by sporting organisations because, first and foremost, athletes are people whose wellbeing and safety need to be at the forefront of their athletic journey. A recent Australian Human Rights Commission review into Gymnastics in Australia identified 'a "win-at-all-costs" culture that prevailed across the sport and found that this created unacceptable risk for the safety and wellbeing of very young gymnasts'.[28] Also, the Gymnastics New Zealand Independent Report,[29] outlines there was a fear of disclosing injuries to coaches and training while injured. However this contradicts the IOC consensus statement on youth athletic development, which clearly states: 'No youth athlete should compete when in pain or not completely rehabilitated and recovered from an illness or

injury.'[4] Other reviews into abuse of athletes worldwide are being conducted or have been published in countries including Japan,[30] and the United Kingdom.[31] We will continue to see a culture of long-term recurring injury, burnout, mental ill-health and abuse, if physical health, including prevention of injury, is not prioritised.

Performance

Many factors contribute to athletic performance, including the athlete's psychological and physical health, the athlete–coach relationship and technical, tactical and physical attributes.[32] Injuries and illnesses have a detrimental impact on team and individual athletic success.[6] Several studies have shown that athlete availability is critical to team success in track and field[33], football[34] and basketball.[35] Pre-competition[36] and in-competition[37] injuries have both been associated with failure to achieve key performance indicators.

Researchers are beginning to investigate this area of health and performance in pre-elite athletes. One recent study explored the effect of injury on ranking position in young elite athletes in athletics, cross-country skiing and orienteering using a weekly, web-based injury questionnaire; a significant difference between top-ranked (3.6%) and middle-ranked (2.3%) athletes compared to low-ranked athletes (11.3%) for substantial injuries was reported.[38] Ranking position was determined by each sport according to past competition results, with the top ranked athletes being better performers. Substantial injury was defined as an injury leading to moderate or severe reductions in either training volume, performance or complete inability to participate in sport. Larruskain et al.[39] recently reported their findings from a prospective six-season injury surveillance study at an elite football academy. They demonstrated that injuries were negatively associated with player progression through the academy pathway towards reaching the First team. This type of research, demonstrating the negative impact injury has on performance strengthens the argument for more investment in injury prevention strategies for the pre-elite athletic population.

Classification of injury prevention in sport

Natural history of disease

In order to understand how to prevent injury it is important to understand the 'natural history of disease', which is the progress of a disease in an individual, from onset to recovery, disability or death, without intervention.[40] According to Gordis,[37] there are four main stages in the natural history of disease. The first is the 'susceptibility stage', when risk factors (such as playing netball) increase the chance of injury. The second stage is 'subclinical', in which the athlete may be pain-free but pathological changes begin, such as inflammation of a growth plate. In the third stage, 'clinical', signs and symptoms become apparent, such as Achilles insertional pain and stiffness. Then, in the fourth stage of 'recovery, disability or death', the athlete stops playing netball and suffers an ongoing disability. Therefore, injury prevention interventions must be targeted according to the stage of disease.

Categorisation of prevention in sport

Injury prevention intervention classification has been described in two ways:[41] by observation of pathology and by risk indicators identified in athletic populations. When considering pathology, the most effective form of intervention is preventing the initial development of disease by immunisation or reducing exposure to a risk factor.[40] Classification of this type of prevention generally describes 'primary prevention'. 'Secondary prevention' is at the 'clinical' stage and involves early detection of existing disease to reduce severity and complications, such as screening for cancer; 'tertiary prevention' involves reducing the impact of the disease, such as through rehabilitation for a muscle injury.[40] When focusing on risk factors, injury prevention interventions are classified as 'universal', 'selective' or 'indicated'. Universal measures are recommended for everyone playing sport; examples include good hydration, adequate rest and use of protective equipment. Selective injury prevention is for subgroups based on sex, age, sport etc. Athletes in this subgroup do not possess any individual risk factors but are at risk because of their subgroup. An example of this is knee injury prevention neuromuscular programs for female adolescent football players. Finally, indicated injury prevention interventions are for individuals with risk factors that place them at higher-than-average risk of developing an illness or

injury. These risk factors can include previous injury, hamstring weakness and cardiac irregularities, among others, and are often identified through periodic health evaluations.

Models of prevention

The van Mechelen 'sequence of prevention' model

The van Mechelen model (Figure 3) was developed to improve the understanding of sports injuries and create a scientifically based prevention strategy.[42] Guidelines were established for injury surveillance and reporting, such as expressing injury incidence as the number of sports injuries per exposure time and the need for consistent 'sports injury' and 'sports participation' definitions. The model consists of four stages. Firstly, the extent of the sports injury problem must be identified and described, outlining incidence and severity. Secondly, contributing factors and mechanisms of injury must be determined. Based on these findings, the third step is to introduce a preventative measure; and, finally, the intervention is evaluated by repeating step one. As injury prevention research has evolved over time, the need to further develop this model has become apparent.

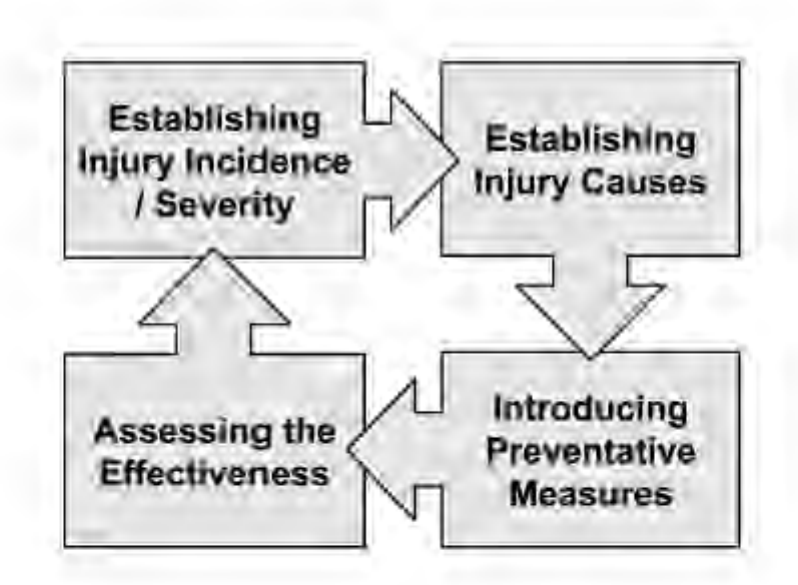

Figure 3: The 'sequence of prevention' of sports injuries.

Translating Research into Injury Prevention Practice (TRIPP)

Translating Research into Injury Prevention Practice (TRIPP),[43] now a well-established framework, consisting of six stages and is an expansion of the van Mechelen model (Figure 4).[42] It will provide the foundation for our investigation into injury prevention in pre-elite athletes as it has been promoted as an approach that will lead to real-world injury prevention gains.

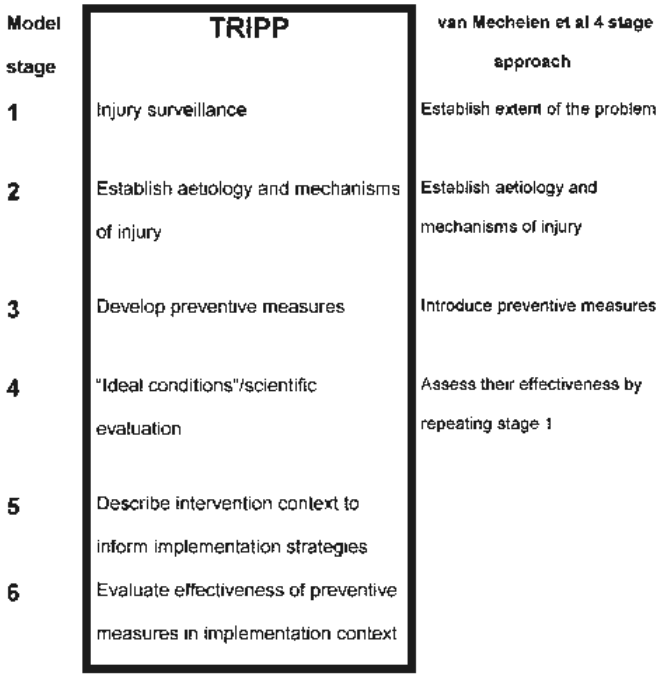

Figure 4: The TRIPP framework compared to the four-stage van Mechelen approach.

Stage One focusses on establishing valid and reliable methods of injury surveillance to allow for routine and ongoing monitoring and reporting of sports injuries. The objective of Stage 2 is to understand the aetiology of injuries to ensure injury prevention interventions target the specific cause of injury. Stage 3 was introduced by Finch[43] to develop potential solutions to the injury problem based on evidence-based practice. Ideally, a multidisciplinary team including the adopters (i.e., those who will decide to use the intervention) and implementers (i.e., those who will deliver the implementation) should develop the injury prevention intervention together. Stage 4 involves assessing the injury prevention intervention under 'ideal conditions' – controlled, targeted and well-resourced. Stage 5 was also introduced by Finch[43] to plan implementation in the real-world to encourage behavioural change. Finally, Stage 6 involves implementing the injury prevention intervention in the real world and evaluating its effectiveness. In the following section we will address each of the stages in detail, examining evidence and application to date within pre-elite level netball, the focus of our investigations.

TRIPP Stage 1 (Injury surveillance)

High-quality injury surveillance information is crucial for informing all other stages of injury prevention. Valid and reliable methodologies must be used to allow for routine, ongoing monitoring

and reporting.[44-46] The recently published IOC consensus statement, *Methods for Recording and Reporting of Epidemiological Data on Injury and Illness in Sport 2020*, outlines a new Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) checklist. It provides recommendations for defining and classifying health problems, severity of health problems, capturing and reporting athlete exposure, expressing risk, burden of health problems, study population characteristics and data collection methods.[47] Applying these recommendations when fulfilling TRIPP Stages One and Two will ensure accurate injury surveillance that will guide the remaining TRIPP stages to achieve injury prevention.

Traditionally, injury surveillance studies have used time loss from sport for defining the occurrence of an injury.[48] This approach does not capture the full impact of overuse injuries, as athletes can often continue to train and compete despite ongoing symptoms.[49] Whalan et al.[50] captured self-report data from 25 semi-professional football teams using the HPQ, which identifies any health problem regardless of time loss. They demonstrated the risk of a time loss injury was 3.6 to 6.9 times higher when preceded by a 'minor' and 'moderate' non-time loss complaint. Earlier detection using the HPQ can lead to early intervention, which may reduce the burden and severity of injury.[51]

This thesis will investigate the use of different injury data collection methods, i.e., athlete self-report and clinical examination injuries in netball to identify both, time loss and non-time loss injuries.[52] The athlete self-report method will provide us with prevalence measures and the clinical examination method will result in incidence rate measures. Both measures can be useful depending on the goals and circumstances of the study. Nielsen et. al.,[53] recommends incidence-based measures be used for assessing aetiology and prevention strategies, whereas prevalence-based measures be used for establishing treatment needs and assessing athlete availability.

Application of TRIPP Stage 1 in pre-elite netball

A recent systematic review[54] of injury surveillance in netball identified 45 articles, the earliest publication being 35 years ago, in 1986.[55] Eighty-seven per cent of these studies were conducted in Australia, New Zealand or South Africa. They consisted of prospective studies over one or more playing

seasons (n=14, 30%), prospective studies at tournaments (n=6, 13%), retrospective studies (n=9, 20%) and studies accessing hospital and insurance databases (n=17, 37%).

Four studies have reported prospective injury rates for pre-elite netball athletes during a season or at a tournament. The ankle and knee have been the most frequent sites of injury during an elite & pre-elite 2013 netball season,[56] the 2009 South African Netball Championships,[57] and the 1995 New South Wales State Netball Championships.[58] Ankle sprains were the most frequent injuries recorded by Hopper and Elliot[59] at the 1988 Australian National Championships, followed by shin/calf injuries. The three tournament studies[57-59] defined an injury as any complaint requiring medical attention, whereas the study reporting pre-elite injuries during a netball season used a time loss injury definition. These studies indicate that injury prevention strategies should continue to focus on the ankle and knee, but it is imperative that comprehensive standardised injury surveillance[48] for the target population is always established prior to introducing an injury prevention strategy.

TRIPP Stage 2 (Establish aetiology and mechanisms of injury)

In order to prevent injury, we need to understand what causes or contributes to injury.[43] In 1994, Meeuwisse[60] presented a multifactorial model of athletic injury aetiology. It describes an interaction of intrinsic risk factors (i.e., age, strength, previous injury), extrinsic risk factors (i.e., equipment, weather conditions, rules) and an inciting event to cause injury. In 2005, Bahr and Krosshaug[61] expanded on Meeuwisses's model to include an expanded biomechanical approach and a focus on sport-specific characteristics (Figure 5).

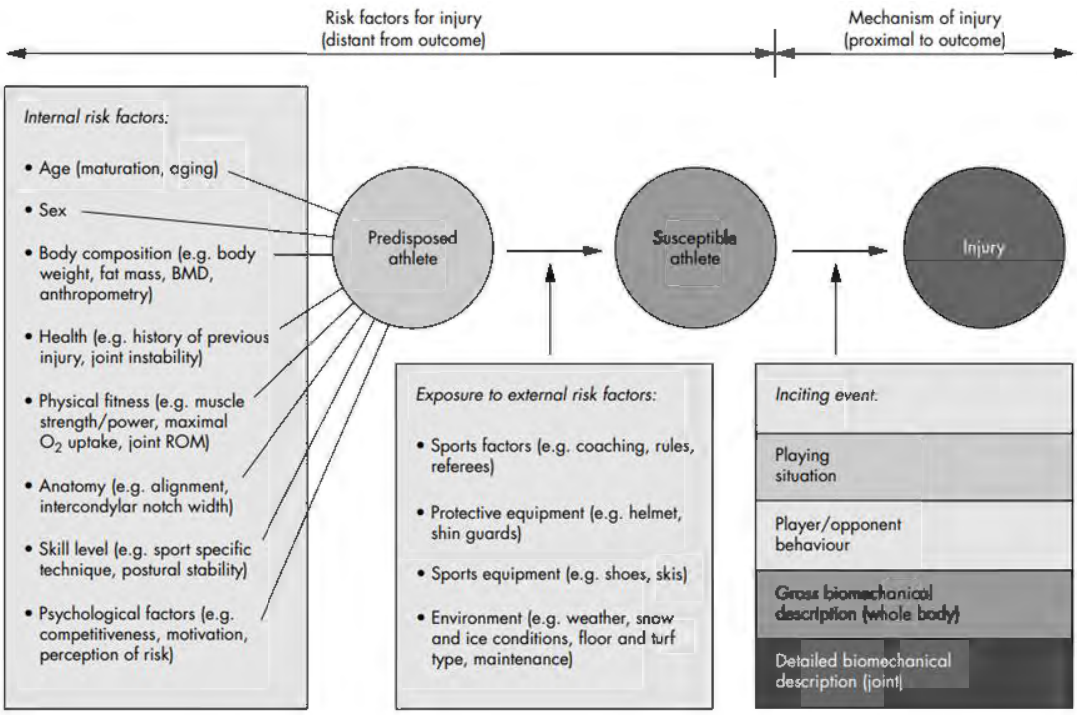

Figure 5: Comprehensive model for injury causation. BMD, Body mass density; ROM, range of motion. Reprinted from Bahr & Krosshaug.[61]

This model demonstrates many contributing factors to injury; however, if each risk factor is assessed separately without controlling for other risk factors, it will not result in a clear understanding of how each contributes to injury.[60] A systems-based research approach, as outlined by Hulme et al.,[62] is required for a better understanding of causation, but discussion and critical analysis of this is beyond the scope of this thesis.

Application of TRIPP Stage 2 in pre-elite netball

All four pre-elite netball studies previously described[56-59] collected aetiology and mechanism of injury data. Age,[56,58,59] level of competition,[56-59] playing position,[56,57,59] injury history,[57-59] mode of onset,[57-59] time of onset,[57,59] footwear and use of tape or a brace[58,59] and mechanism of injury[58,59] data were routinely collected. Pickering Rodriguez et al.[56] were particularly interested in examining the relationship between lower-body stiffness and injury incidence, so they also collected active and quasi-static stiffness data for the lower body. Adherence to an injury prevention strategy was also recorded by Hume and Steele,[58] and Hopper and Elliot[59] included a podiatric assessment and recorded the prevalence of existing injuries reported by players at the start of the championships.

These four studies have provided us with a better understanding of what contributes to pre-elite netball injuries, but there is a need to expand this knowledge to aid future injury prevention strategies. There was no relationship between lower-limb stiffness and injury in pre-elite athletes.[56] Hopper and Elliot,[59] reported that most injuries occurred in the second quarter of the game (32.7%) whereas Langeveld et al.[57] found most injuries occurred in the third quarter (26%). The most frequent mechanisms of injury were 'incorrect landing'[59] and 'contact with a player'.[57,59] Additionally, according to Langeveld et al.[57] the position of Goal Defence sustained the most injuries (22%).

Coetzee et al.[63] reported additional data from the tournaments previously described by Langeveld et al.[57] They identified that a cement surface had a 1.9 times higher injury rate than a synthetic surface and reported that 52% of injured athletes did not perform any core stability sessions and 58% did not perform neuromuscular control sessions, but 64% did partake in flexibility training. Hume and Steele[58] also found a lack of awareness of injury prevention strategies, with 28% of injured athletes not knowing what a wobble or balance board was.

The mechanism of injury data presented by Hume and Steele[58] is a good example of why we need consistent definitions and methodology, as outlined by the IOC consensus statement.[47] They reported on 'netball action at the time of injury', the most frequent responses being 'other' (21%) and 'combinations of movement' (18%). Neither of these responses provide us with a better understanding of mechanism of injury. It must be acknowledged that the data for this study were collected 26 years ago and our understanding of data collection requirements has improved greatly since then.

Several studies have examined the relationship between netball biomechanics and injury, but none specifically for pre-elite athletes.[27,64,65] Landings have been identified as a high-risk activity for Anterior Cruciate Ligament (ACL) injuries in netball.[65] Using unanticipated 180º turn agility sprints, Maulder[66] identified a dominant limb asymmetry of greater than 10% as having moderate association with injury.[66] Downs'[54] systematic review identified a lack of studies reporting the circumstance and mechanisms of injury in order to provide more meaningful data for developing prevention strategies.

TRIPP Stage 3 (Develop preventive measures)

This stage involves identification and development of potential solutions to the injury problem guided by TRIPP Stage 2, in which potential risk factors have been identified.[43] A multi-disciplinary approach is required to consider all possible injury prevention strategies. Following the Intervention Development Process (IDP)[67] is one way of satisfying Stage 3 of TRIPP. This involves combining research evidence and clinical experience as well as engaging end-users early to develop an injury prevention strategy. The IDP was successfully used to create a lower-limb injury prevention exercise training program ('FootyFirst') for community Australian football.[67] This process recognises that research evidence alone is insufficient to implement injury prevention strategies[68] and ensures that the best available scientific evidence is combined with practitioner expertise and end-user values.

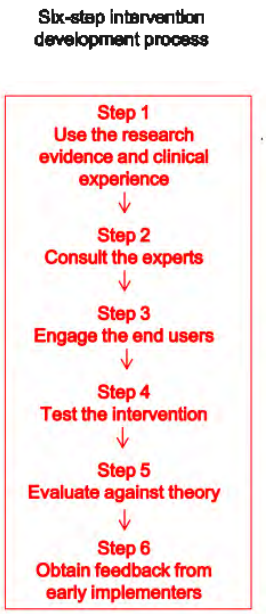

Figure 6: Six-step intervention development process. Reprinted from Donaldson et al.[67]

Application of TRIPP Stage 3 in pre-elite netball

There is no evidence of the six-step IDP being applied in pre-elite netball. Two observational studies have been identified that could be considered to partially satisfy Step 4 of the IDP. Fox et al.[69] used pre-elite athletes to assess whether biomechanical errors identified during a single-leg squat correlated with errors identified during a netball-specific leap landing. Landings have been identified as a high-risk activity for ACL injuries in netball. In elite-level netball 13 out of 16 (81%) cases occurred when an

athlete was landing from a jump.[65] Because of this association between landing and ACL injury, they concluded the single-leg squat may be a useful movement screen for identifying netball players who may be at risk of sustaining an ACL injury. Sinclair et al.[70] investigated the effect of knee bracing on knee joint kinetics and kinematics using pre-elite netball athletes. They found no difference in joint kinetics but an increase in subjective knee stability when wearing the brace. For these two studies to be effective, researchers, clinicians and end-users need to incorporate this work into the intervention development process to create an implementable intervention.

TRIPP Stage 4 ('Ideal conditions'/scientific evaluation)

Once the intervention is developed in TRIPP Stage 3, its efficacy must be assessed in a controlled and targeted manner. This is usually in the form of a randomised controlled trial or a cohort study. The CONSORT (Consolidated Standards of Reporting Trials) statement is the gold standard for transparent reporting of design, analysis and interpretation for randomised controlled trials.[71] The STROBE statement provides guidelines for reporting a cohort study.[72] These studies, even if they are field-based, are often conducted in an artificial environment in which the investigators deliver the intervention, participating teams and players are provided with staff and resources and participants are provided with incentives and reminders.[43] Most often, once the research is completed the injury prevention strategy is not continued, because very few sporting associations possess the human resources and/or finances required to maintain the intervention.[73] To prevent this from occurring, TRIPP Stage 5 and Stage 6 were introduced to encourage a greater emphasis on implementation of an injury prevention strategy.[43]

Application of TRIPP Stage 4 in pre-elite netball

No studies have investigated the efficacy of injury prevention strategies in pre-elite netball. Two publications were identified using university student participants to test the efficacy of two injury prevention training programs.[74,75] One of the programs assessed the efficacy of an eight-week barefoot training programme on ankle stability, agility and speed;[74] the other assessed the efficacy of a six-week neuromuscular/safe-landing training program called 'Down to Earth' for reducing injury incidence.[75] The barefoot training resulted in a significant improvement in agility and ankle stability. The barefoot group significantly improved their performance in the 505-Agility test to the left ($p = 0.01$; $d = 1.04$)

and the right (p = 0.002; d = 1.4); As well as single leg balance as assessed on the Biodex Balance System, showing superior overall stability of the right leg (p = 0.01; d = 1.62), anterior-posterior stability of the right leg (p = 0.01; d = 1.36) and medial-lateral stability of the right leg (p = 0.04; d = 1.14).[74] The 'Down to Earth' program resulted in a significant reduction in training injuries during the six weeks following the intervention period. Ten (38%) injuries were recorded for the intervention group and 15 (75%) were recorded for the control group (RR 0.01, 95%CI 0.001-0.376; p=0.02).[75] However, caution is advised when interpreting these results, as there were 32% (n=8) fewer athletes in the intervention group and only an athlete self-report injury definition was employed. This lack of evidence for injury prevention strategies in pre-elite netball athletes must be addressed.

TRIPP Stage 5 (Describe intervention context to inform implementation strategies)

TRIPP Stage 5 is essential for determining whether efficacy research is translatable into actions that can be implemented in the real-world context of sport. Firstly, a clear understanding of what the current safety behaviours are, and whether they need to change, is required. Secondly, if safety measures are not being adopted, we need to know why. Gaining an insight into motivators/barriers to uptake and an understanding of the knowledge and attitudes of players, coaches and sports bodies towards injury and prevention of injuries is essential for planning implementation.[43] Sports injury interventions are often ineffective because they are not widely accepted and adopted.[76] A number of tools exist to facilitate the implementation of injury prevention interventions;[76-82] intervention mapping (Step 5), the Reach, Effectiveness, Adoption, Implementation and Maintenance (RE-AIM) framework and concept mapping are examples of implementation strategies recently used in the sports injury context. There has been recent growth in sports medicine studies utilising these processes but they need to become standardised for all injury prevention interventions to achieve a reduction in injury/illness rates.[83]

Implementation sciences

Intervention mapping (step 5)

Intervention mapping (IM) is a protocol for systematic planning for behavioural change based on theory and evidence.[80] IM is a six-step process that starts with problem identification and ends with problem solving or reduction. There are several tasks in each of the six steps. It is possible to use IM (Step 5)

independently to complete TRIPP Stage 5 for planning the adoption, implementation and sustainability of an injury prevention intervention in the real world.[79] The tasks for this stage include:

1. Identification of potential adopters
2. Identification of potential implementers
3. Establish an implementation planning group with representatives from adopters and implementers
4. State intervention use outcomes and specify performance objectives for reach, adoption and implementation
5. Specify determinants of reach, adoption and implementation
6. Select strategies for reach, adoption and implementation that are theory-informed, evidence-based and context-specific
7. Design interventions for reach, adoption and implementation.

This IM protocol has been used to develop plans for the 'Mayday' neck and spinal injury prevention policy in rugby union[84] as well as the FootyFirst exercise training programme to prevent leg injuries in Australian football.[79]

RE-AIM (reach, effectiveness, adoption, implementation and maintenance) framework

This framework is primarily used as an evaluation tool for intervention studies, but it can also be used as a planning tool alongside TRIPP and other implementation strategies. It was developed on the basis that behaviour change will only occur if interventions are available to the group of interest, adopted by them, used as they were intended and then sustained. There are five components:

- **Reach** is the absolute number, proportion and representativeness of individuals willing to participate in the intervention. Planning should consider the demographics of the intended population and potential barriers that will limit success in reaching the target population.
- **Effectiveness** is the impact the intervention will have on important outcomes, including potential negative effects. This component determines if the intervention is evidence-based or a new innovation and key stakeholders should be consulted to determine how success will be defined and measured.
- **Adoption** is the absolute number, proportion and representativeness of implementers and adopters that are willing to initiate the intervention. Consideration should be given to the percentage of target population that will initiate the intervention as well as to what the greatest barriers to adoption will be.
- **Implementation** refers to the consistency, cost and adaptations made during delivery. Planning needs to ensure the intervention can be delivered consistently but also has the flexibility to change mid-course if required.
- **Maintenance** is the ability of the intervention to become institutionalised or part of routine practice. Plans should be made to support initial success and prevent drop-off and to determine whether resources would assist in providing long-term support.

The RE-AIM framework has been used to successfully implement several sports injury prevention interventions, such as a safe-landings programme for junior netballers[85] and community footballers.[86]

Concept mapping

Concept mapping has been used for injury prevention in public health[87] and in sport.[88] It was developed in the 1980s using qualitative and quantitative methods to enable a group of people to articulate ideas and have these ideas graphically and objectively represented.[89] The structured process involves

brainstorming relevant ideas, after which each participant is asked to sort the ideas into groups that make sense to them and then to rate each idea for how important they think it is and how difficult they think it will be to implement that idea. The Concept Systems Global MAX[90] website is an effective way of facilitating this process.

Knowledge and attitudes questionnaire

Exploring the knowledge and attitudes of players, coaches and sports organisations in relation to the frequency, causes and prevention of injuries as they occur in their sport is an important part of implementation planning. Shamlaye et al.[91] used a web-based nationwide survey of 538 football coaches to discover the attitudes, beliefs and factors influencing their adherence to the FIFA 11+ injury prevention programme. One finding was that coaches with less experience may be less likely to use the 11+, meaning this population should perhaps be the target for future education workshops.

Application of TRIPP Stage 5 in pre-elite netball

There is no evidence of TRIPP Stage 5 being applied in a pre-elite netball population. In total, four netball studies focusing on implementation have been identified: four in community netball[85,92-94] and one involving secondary school coaches and players.[95] Two of the community netball studies were conducted to assess the efficacy and implementation of injury prevention-related coach education.[85,92] Components of the RE-AIM framework[92] and the full RE-AIM framework[85] were applied when seeking feedback from community coaches after attending an education session. Part of the RE-AIM framework was also applied in another community netball study, reporting the implementation of the Netball KNEE program.[94] Fidelity was found to be poor, with only 12–18% of recommended activities performed as intended across three age groups. The final community netball study used a questionnaire developed from the Theory of Planned Behaviour to assess player behavioural factors associated with players' intentions to learn correct landing technique during coach-led training sessions.[93] The secondary school study investigated coach and player attitudes to injury.[95] Of the 226 players surveyed, 87% (n=196) reported hiding or downplaying an injury. Similarly, of the 117 coaches, 87% (n=102) had witnessed a player continue to play on when they thought they should not have. The absence of

more implementation studies such as these is indicative of why there is a lack of evidence for effective 'real-world' injury prevention strategies in netball.

TRIPP 6 (Evaluate effectiveness of preventive measures to implementation context)

This stage determines how effective the scientifically proven interventions are when applied to the real-world context. The intervention is implemented and its effectiveness is evaluated.[43] A good example of this was the promotion of protective eyewear for squash players.[96] The protective eyewear promotion (PEP) project, consisting of availability of eyewear and educational material, resulted in 'PEP' players being 2.4 times more likely to wear eyewear than the control group. The implementation of this successful strategy was guided by planning (i.e., TRIPP Stage 5) conducted by some of the same researchers using principles of behaviour change.[82] When the International Sporting Federation Chief Medical Officers were surveyed, they valued TRIPP Stage 5/6 research most highly out of all TRIPP stages.[97] However there is a lack of this type of research, with a systematic review revealing that between 2007 and 2009 only 5% of sports injury prevention research involved implementation (i.e., TRIPP Stage 5) or effectiveness (i.e., TRIPP Stage 6) studies.[98]

Application of TRIPP Stage 6 in pre-elite netball

To date, there have not been any studies evaluating the effectiveness of injury prevention strategies (i.e., TRIPP Stage 6) applied to the netball pre-elite population. We have identified one netball effectiveness study investigating the effect of an integrated functional stability program on injury rates in an international netball squad.[99] It is a good example of applying the ecological systems theory, ensuring athletes, support staff, coaches and management have a role to play in injury prevention. It is of concern that netball has been played for over 100 years[100] and yet there is only one study assessing the effectiveness of an injury prevention strategy in a 'real-world' setting.

Knowledge gaps

There is a significant lack of sports injury prevention research that has real-world relevance.[98] When all sports injury prevention publications between 1938 and 2010 were retrieved (n=11,859), only 4% assessed the effectiveness of implementation of their research findings.[98] Most research addresses the early stages of the TRIPP framework with little regard for implementation of findings, which limits injury prevention potential. For injury prevention intervention implementation to be successful, we need to acknowledge that effective interventions are multifaceted and complex and must target multiple socioecological levels.[76,101] In both community and high-performance sport there are often many levels of hierarchy, with many stakeholders at all levels who can influence the success or failure of an injury prevention intervention. Therefore, the development of interventions and their implementation strategies must be holistic with a whole-of-sport and whole-of-industry approach. Furthermore, when targeting the pre-elite population, interventions and their implementation strategies need to be specific to that population to succeed.[67]

Thesis aim

The purpose of this thesis is to develop a holistic strategy to reduce injuries in pre-elite athletes, using netball as an exemplar sport. This strategy was trialled within one of our national sporting organisations (i.e., Netball Australia), working closely with the sport to determine their injury profile and then continuing to develop, plan and implement effective injury prevention interventions. This research, using netball as an example will provide much-needed guidance for injury prevention in pre-elite athletes to reduce injuries sustained throughout their development pathway. Stemming from this will be the long-term aim of supporting robust elite athletes achieving greater success with less injury.

Thesis structure

This thesis follows the TRIPP framework to develop a process for real-world injury prevention gains in the pre-elite population, using netball as an exemplar sport. The TRIPP framework is made up of a series of six sequential steps focused on developing and implementing one preventative strategy. Prior to the commencement of this research, Netball Australia undertook injury surveillance at the 2017 17/U

& 19/U Australian National Netball Championships (ANNC). It had also developed focused activities in this area, including, a neuromuscular warm-up designed to prevent injury, and prophylactic ankle taping was encouraged. While all stages of the TRIPP framework are necessary, it was not possible to apply the steps sequentially for a single preventative strategy because there were multiple injury types to address, and some preventative strategies were already in place. Instead, we used each step of the TRIPP framework with a pragmatic sequence approach (see Figure 6 below for a summary of the studies in relation to the TRIPP framework).

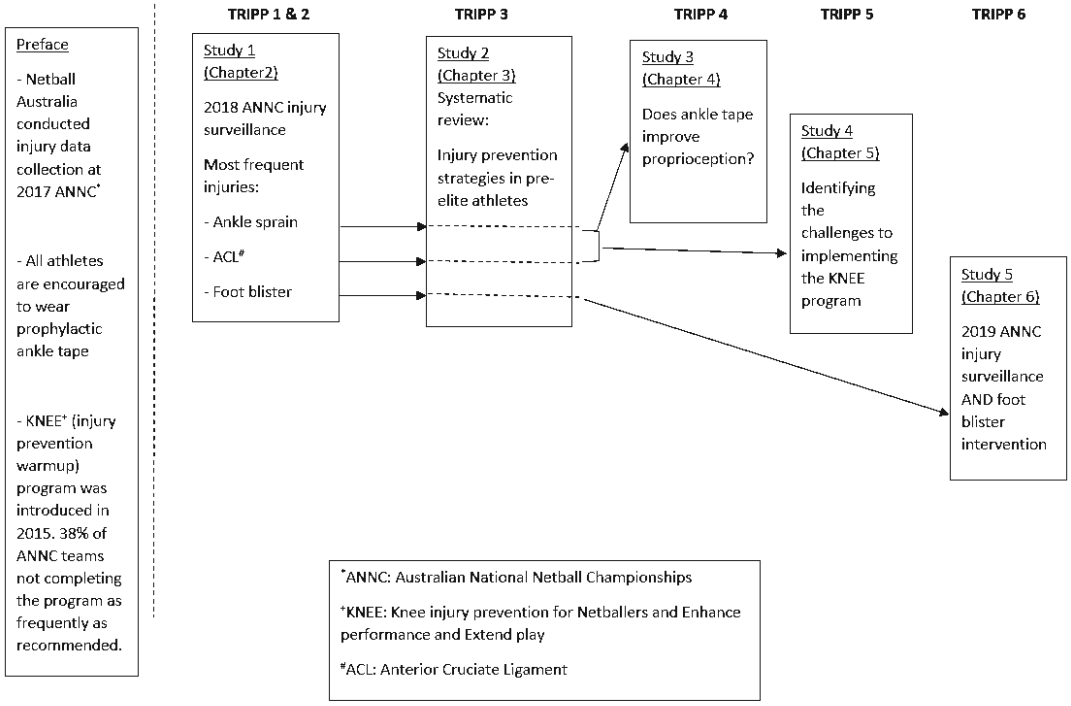

Figure 7: Schematic representation of the thesis as relates to the TRIPP approach.

This thesis has seven chapters. Chapters 2, 3, 4 and 5 incorporate published works and the research work reported in Chapter 6 has been submitted for publication. Chapter 7 is an overall discussion of the findings from each study and the implications of the study findings for future research and practice.

Chapter 2 presents TRIPP Stage 1 (Injury surveillance) and TRIPP Stage 2 (Establish aetiology and mechanisms of injury) in the form of injury surveillance findings of the 2018 17/U & 19/U Australian National Netball Championships.

Published as: **Smyth E**, Piromalli L, Antcliff A, et al. A prospective study of health problems at the 2018 17/U and 19/U Australian National Netball Championships with comparison of surveillance methodology. *J Sci Med Sport*. 2020;23:215-21.

Chapter 3 is a systematic review of injury prevention intervention in pre-elite athletes. This is a vital part of TRIPP Stage 3 (Develop preventive measures).

Published as: **Smyth E**, Newman P, Waddington G, et al. Injury prevention strategies specific to pre-elite athletes competing in Olympic and professional sports – a systematic review. *J Sci Med Sport*. 2019;22:887-901.

Chapter 4 reports the findings of a randomised controlled trial investigating the effect of ankle tape on proprioception. Ankle taping is routinely used in netball to prevent ankle sprains but the mechanism for its effectiveness is not well understood. This study fulfils TRIPP Stage 4 ('Ideal conditions'/scientific evaluation).

Published as: **Smyth E**, Waddington G, Witchalls J, et al. Does ankle tape improve proprioception acuity immediately after application and following a netball session? A randomised controlled trial. *Phys Ther Sport*. 2021; 48:20-25.

Chapter 5 presents TRIPP Stage 5 (Describe intervention context to inform implementation strategies). Netball Australia has developed a neuromuscular warm-up called the KNEE program to prevent lower-limb injuries. This chapter introduces concept mapping to improve the implementation of this program.

Published as: **Smyth E**, Appaneal R, Drew M, et al. Identifying the challenges to implementing a neuromuscular warm-up in pre-elite netball. *Int J Sports Sci Coach*. 2021;16:913-24.

Chapter 6 reports injury surveillance results for the 2019 17U & 19U Australian National Netball Championships following the implementation of an injury prevention strategy. This process is TRIPP Stage 6 (Evaluate effectiveness of preventive measures in implementation context).

Submitted for publication in the peer-reviewed journal *Translational Sports Medicine*.

Research Questions

Chapter 2 Study 1: What is the injury incidence and prevalence for 17/U & 19/U netball athletes competing at the 2018 Australian National Netball Championships?

Chapter 3 Study 2: What injury prevention interventions have been determined to be effective in pre-elite athletes competing in Olympic and professional sports?

Chapter 4 Study 3: Does ankle tape improve proprioception acuity in pre-elite netball athletes immediately after application and following netball training? Is there any difference in proprioception if ankle tape is self-applied compared to being applied by a Sport and Exercise Physiotherapist?

Chapter 5 Study 4: What are the barriers to implementing the 'KNEE' injury prevention strategy in a pre-elite netball population?

Chapter 6 Study 5: What is the injury incidence and prevalence for 17/U & 19/U netball athletes competing at the 2019 Australian National Netball Championships? Can foot blister incidence be reduced at the 2019 17/U & 19/U ANNC compared to the 2018 17/U and 19/U ANNC by implementing a foot blister prevention intervention?

Chapter 2 Injury surveillance and establishing aetiology and mechanism of injury (TRIPP 1 & 2)

Published work

This chapter is based on a manuscript that has been published in the Journal of Science and Medicine in Sport.

> **Smyth E**, Piromalli L, Antcliff A, et al. A prospective study of health problems at the 2018 17/U and 19/U Australian National Netball Championships with comparison of surveillance methodology. *J Sci Med Sport*. 2020; 23:215-21.

At the time of publishing, there were no studies reporting injury rates specifically in pre-elite netball players in the previous decade. The TRIPP framework provides a structure for developing and implementing injury prevention strategies. The critical first stage of the TRIPP process is injury surveillance to determine which injuries have the highest burden to direct future injury prevention strategies. The second TRIPP stage is to determine aetiology and mechanisms of injury to also direct how these costly injuries may be prevented.

None of the 192 pre-elite athletes have constant physiotherapy access throughout the year like they do at the ANNC, which limits surveillance of accurate 'whole of year' injury data. Therefore, conducting injury surveillance at a tournament where all athletes have access to a team physiotherapist was considered a practical method for obtaining injury information for this population within real-world constraints. An alternative method of injury surveillance that is not reliant on access to a health professional, the Health Problems Questionnaire (HPQ),[20] was also trialled. This injury surveillance tool is a self-report method that has been found to be sensitive and valid in documenting acute injuries, overuse injuries and illnesses.[102,103] The HPQ self-report injury surveillance method was used in addition to medical attention injury surveillance to allow for injuries to be recorded for four weeks following the tournament and to compare percentage of agreement between the two surveillance tools. The medical attention injury records were also designed to capture mechanism of injury, onset of injury

(i.e., new versus recurrent) and nature of injury (i.e., trauma versus overuse). This additional information will help inform future injury prevention strategies.

The aim of this study was to describe the injuries that occurred over the six-day 2018 17/U & 19/U ANNC, compare the injury profile between age groups, describe contributing factors, compare two injury surveillance methods and determine whether exposure to the tournament alters the health of participants in the following four weeks.

Co-authors' declaration

Declaration of Co-Authored Publications

UNIVERSITY OF CANBERRA

For use in theses which include co-authored publications. This declaration must be completed for each co-authored publication and to be placed at the start of the thesis chapter in which the publication appears, or as a preface to the thesis.

Declaration for Thesis Chapter Two

Publication: "A prospective study of health problems at the 2018 17/U and 19/U Australian National Netball Championships with comparison of surveillance methodology"

DECLARATION BY CANDIDATE

In the case of Chapter Four, the nature and extent of my contribution to the work was the following:

Nature of Contribution	Extent of Contributions (%)
Conception and design of the research proposal	80%
Data collection	50%
Analysis and interpretation of the findings	70%
Writing the paper and critical appraisal of content	70%
Corresponding author for journal communication and publication peer-review process.	100%

The following co-authors contributed to the work:

Name	Nature of Contribution	Contributor is also a UC student (Yes/No)
Gordon Waddington	Conception and design of the research proposal Data collection Analysis and interpretation of the findings Writing the paper and critical appraisal of content	No
Alanna Antcliff	Conception and design of the research proposal Analysis and interpretation of the findings	No
Phil Newman	Writing the paper and critical appraisal of content	No
Juanita Weissensteiner	Writing the paper and critical appraisal of content	No
Laura Piromalli	Conception and design of the research proposal Analysis and interpretation of the findings	No
Michael Drew	Conception and design of the research proposal Analysis and interpretation of the findings Writing the paper and critical appraisal of content	No

_____ _17/09/2021_____

Candidate's Signature Date

DECLARATION BY CO-AUTHORS

The undersigned hereby certify that:

Declaration of Co-Authored Publications

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(1) the above declaration correctly reflects the nature and extent of the candidate's contribution to this work, and the nature of the contribution of each of the co-authors.
(2) they meet the criteria for authorship in that they have participated in the conception, execution, or interpretation, of at least that part of the publication in their field of expertise;
(3) they take public responsibility for their part of the publication, except for the responsible author who accepts overall responsibility for the publication;
(4) there are no other authors of the publication according to these criteria;
(5) potential conflicts of interest have been disclosed to (a) granting bodies, (b) the editor or publisher of journals or other publications, and (c) the head of the responsible academic unit; and
(6) the original data are stored at the following location(s) and will be held for at least five years from the date indicated below:

[Please note that the location(s) must be institutional in nature, and should be indicated here as a department, centre or institute, with specific campus identification where relevant.]

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A prospective study of health problems at the 2018 17/U and 19/U Australian Netball National Championships with comparison of surveillance methodology

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Original research

A prospective study of health problems at the 2018 17/U and 19/U Australian National Netball Championships with comparison of surveillance methodology

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ABSTRACT

Objective: To investigate the incidence, site, nature and cause of injuries sustained during and four weeks following the 2018 Australian National Netball Championships (ANNC's) using medical attention and self-report surveillance tools.
Design: Prospective cohort study.
Method: Injuries were recorded prospectively using medical attention and self-report data collection methods. One hundred and ninety-two athletes competed at the 2018 ANNC's with 96 athletes in each age group (17/U & 19/U).
Results: There were 103 medical attention injuries sustained by 80 athletes resulting in an incidence rate of 89.4 per 1000 player hours. The most frequently recorded medical attention injury diagnoses across both age groups were lateral ankle ligament sprain (n = 14, 13.6%), foot blisters (n = 11, 10.7%), and lumbar pain (n = 10, 9.7%). Ankle sprains (n = 4), anterior cruciate ligament (ACL) ruptures (n = 3) and concussion (n = 3) recorded as the highest sports incapacity injuries. The self-report data collection revealed that 46 (27.2%) athletes arrived at the tournament with an existing self-reported injury/illness and 57 (39.3%) athletes had a self-reported injury/illness at the conclusion of the ANNC (RR 1.44 95%CI 1.05–1.99, p = 0.030).
Conclusion: There are no recent studies reporting injury rates specifically in pre-elite netball players. This study found an incidence rate of 89.4 per 1000 player hours. Ankle sprains are the highest medical attention and sports-incapacity injury in pre-elite netball athletes. Foot blisters and low back pain also feature in the highest medical attention injuries and ACL rupture and concussion were high sports incapacity injuries at the ANNC's. Finally, combining both the medical attention and self-report injury/illness data collection methods identified more injuries/illnesses than the use of one method alone.

Practical implications

- Prevention of ankle sprains and ACL rupture should be a priority. The use of a neuromuscular warm-up such as the Netball Australia 'KNEE' program should be considered.
- Foot blisters are common but can be prevented with load management, appropriate footwear, good hygiene and prophylactic taping.
- Implementation planning of injury prevention interventions must be prioritised.

1. Introduction

Netball is a sport which involves a combination of high-intensity short sprints and agility movements, jumping, landing,

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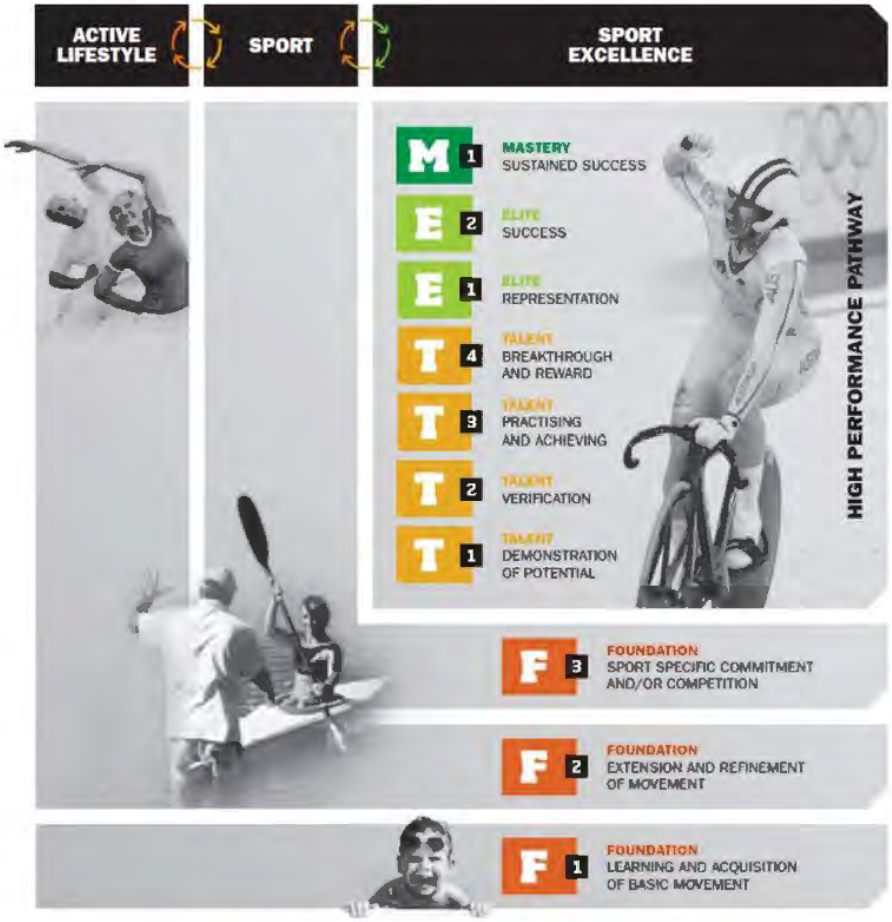

Fig. 1. The integrated FTEM (Foundations, Talent, Elite, Mastery) framework for the optimisation of sport and athlete development. Image courtesy of the Australian Sports Commission, http://www.ausport.gov.au.

passing and catching.[1,2] Given the nature of netball, high injury rates are common[2,4,5] but unlike other sports,[6–8] current pre-elite injury rates are unknown. Pre-elite athletes, as defined by the FTEM (Foundation, Talent, Elite and Mastery) athlete development framework[10] are 'Talent' level athletes (i.e. Talent 3 and 4) commonly emerging from the junior ranks, who have been formally recognised as having future high performance potential and receive limited financial and service support (Fig. 1). Injury has the potential to prevent pre-elite athletes progressing to be elite.[11] The International Olympic Committee (IOC) has released a consensus statement on youth athletic development, outlining challenges to this cohort such as a rapid increase in training load, insufficient rest and recovery, growth and a lack of support services compared to elite athletes.[12] Pre-elite athletes often have competing demands between sports, school sport, club and representative commitments with minimal support to manage individual training loads.[10]

Despite the benefits of regular physical activity, athletes are exposed to injury risk.[5] There is an economic, physical and psychological cost to injury particularly in pre-elite athletes.[11] This may compromise performance resulting in an inability to fulfil full athletic potential with drop out as a possible consequence. This has been demonstrated in Australian track and field athletes where 17.3% of injured athletes retire before the age of 18 due to injury.[6] It is imperative that governing bodies are aware of these risks so injury prevention interventions can be implemented to minimise these risks.[13] The 17/U and 19/U ANNC's is a benchmark tournament for developing netball athletes. An increased injury risk is associated with congested matches (multiple matches in a short period of time) and greater match intensity compared to their local competition in other team sports such as football.[14–16] Consequently, Netball Australia have undertaken thorough injury surveillance at their 17/U and 19/U ANNC to fulfil the first stage of the Translating Research into Prevention Practice (TRIPP) model of prevention.[17]

There are no recent studies reporting injury rates specifically in pre-elite netball players. A combined medical attention/sports incapacity injury incidence rate of 11.3 per 1000 player hours over two seasons of community netball in Western Australia has been reported.[3] Ankle injuries were most common (53.8%), followed by knee injuries (27.7%) and finger/thumb injuries (26.2%). Hopper et al.[18] reported a medical attention injury incidence of 5.4% across five years of community netball in Western Australia, with ankle injuries being most common (84%). A medical attention injury incidence of 23.8 per 1000 player hours was reported during the three day 1995 NSW State netball championships with knee (14%) and ankle (14%) injuries most common.[4] In 2009, across three pre-elite tournaments in South Africa a medical attention injury rate of 500.7 injuries per 1000 player hours was reported.[5] Ankle injuries (34%) were most highly recorded followed by knee injuries (15%).[5]

As demonstrated there are large variations in reported injury rates for the sport of netball. A number of variables could contribute

to this such as whether injuries are recorded from tournament play or weekly matches in-season, the data collection methods used, injury definition and study participants. The very high South African injury rate is most likely the result of using a different definition for athlete exposure. Only the minutes played prior to injury were used for this calculation as opposed to minutes played by all players.

A number of injury definitions have been adopted in previous netball epidemiology papers. The injury definitions concept framework (IDCF) describes them as medical attention, athlete self-report or sports incapacity. No previous netball epidemiology study has used athlete self-report despite its benefits for capturing overuse injuries more accurately[19] and obtaining longitudinal data without reliance on medical personnel to capture the data. The Oslo Sports Trauma Research Centre (OSTRC) Health Problems Questionnaire (HPQ)[20] has been utilised in this study for this purpose. The authors wanted to calculate whether there was an increase in injury rates across the four weeks following the tournament which has been previously described due to a spike in load.[21]

The aims of this paper are to (1) describe the type, location and severity of injuries and illnesses that occur across the six day 2018 17/U & 19/U ANNC and four weeks following the tournament; (2) determine if the injury profile is different between 17/U & 19/U netball athletes; (3) describe contributing factors to injury; (4) compare percentage of agreement when clinical assessment and self-report injury data collection methods are employed and (5) determine whether exposure to the tournament alters the health of participants in the following four weeks.

2. Methods

The incidence of injuries occurring in the 2018 17/U & 19/U ANNC was prospectively studied in 192 netball athletes across 16 teams (17/U, athletes n = 96; 19/U, athletes n = 96). The tournament took place over six consecutive days in April (17th–22nd). Each team played nine matches with two matches played on days one, two and four, and one match played on days three, five and six. A total of one hundred and forty-four matches were played and matches consisted of four, ten minute quarters. The reporting of this study follows the Strengthening the Reporting of Observational studies in Epidemiology (STROBE) statement.[22] Ethics approval was obtained from the Australian Institute of Sport Ethics Committee (Approval number: 20180404). All participants or their parents/guardians provided consent via their Athlete Management System (AMS; Smartabase, Fusion Sport, Brisbane, Australia) account, accessible from personal computers, tablets and smartphones.

Concurrent Injury Definitions Concept Framework (IDCF)[23] definitions were utilised. Clinical examination injuries were defined as any health complaint that required the team physiotherapist to assess, irrespective of time-loss (sports incapacity). Sport incapacity injuries were defined as an injury that required an athlete to miss any duration of match play during the tournament or where the athlete reported a reduction in capacity during the tournament as assessed by the Oslo Sports Trauma Research Centre (OSTRC) Health Problems Questionnaire (HPQ).[20]

The HPQ asks the athlete four key questions around athlete health. These are:

1 Have you had any difficulties participating in normal training and competition due to injury, illness or other health problems during the past week?
2 To what extent have you reduced your training volume due to injury, illness or other health problems during the past week?
3 To what extent has injury, illness or other health problems affected your performance during the past week?
4 To what extent have you experienced symptoms/health complaints during the past week?

All data (clinical examination and athlete self-reported) were collected via a centralised database (Smartabase, Fusion Sport Pty Ltd, Brisbane Australia).[24] Team physiotherapists met with the primary author to discuss injury definitions such as new versus recurrent, trauma versus overuse to ensure consistency. Each medical attention injury/illness recorded in the AMS database by team physiotherapists was assigned a four-character Orchard Sports Injury Classification System 10.1[25] injury diagnosis code, which details the body part and nature of the injury sustained. Additional information was recorded to classify the body side of the injury (i.e. left, right, bilateral, central), date of injury occurrence, training or match environment and the number of days the player was unable to participate both fully and partially in netball training/competition. In addition, the physiotherapist recorded mechanism of injury, court location, position, time of match, number match of the day, tournament day and whether the athlete could continue playing immediately after injury.

Injuries can occur four weeks following a spike in load[21] therefore athletes were asked to complete the HPQ at the start of the tournament, end of the tournament, one week post tournament and four weeks post tournament. Prevalence measures were calculated for each of the four HPQ's. Prevalence of self-report substantial problems and severity of health problems were calculated according to published methods.[20,26,27] We chose to report period prevalence rather than point prevalence for this study as it was over a smaller time period and with the reduced response rate for the third and fourth HPQ's, this approach provides a more accurate interpretation of the data. Averages and confidence intervals were calculated by identifying the athletes that reported any health problem across the four questions for any of the four HPQ's (ie, problems where athletes selected option 2, 3, 4 or 5 in any of the questions at any time). This number of athletes were then divided by the total number of participants. The prevalence of substantial problems was calculated by identifying those who had moderate or severe reductions in training volume or moderate or severe reductions in sports performance or complete inability to participate in sport (ie, problems where athletes selected option 3, 4 or 5 in either Question 2 or 3).

Athlete exposure was captured by Netball Australia nominated national selectors using the AMS (Smartabase, Fusion Sport Pty Ltd, Brisbane Australia). The position, including those not playing was recorded for each quarter of every match. Where there was significant missing data, average team exposure was calculated by multiplying the number of athletes (n = 12) by the number of teams (n = 16) by the number of matches (n = 9) by the number of minutes/match (n = 40).

Descriptive analysis was performed separately and combined for 17/U and 19/U athletes at the 2018 ANNC's. The difference between specified injury variables for 17/U and 19/U were measured by calculating risk ratio. Due to low sample size, Fisher's exact test was used to test for significance. Injury incidence was calculated using the formula: number of injuries/exposure per 1000 h. Incidence Rate Ratios (IRR) were calculated by dividing the 17/U incidence rate by the 19/U incidence rate to compare the 17/U (referent) and 19/U age groups in terms of total injuries and sports incapacity injuries as well as comparing total new/recurrent injuries and traumatic/overuse injuries. A statistical significance level was set a priori, where 95% confidence intervals did not include 1.0 for analyses including rate ratios or incidence rate ratios. A chi-square test was used to compare injury region and nature. Mechanism of injury, court location, position, time of match, num-

ber match of the day and tournament day were not analysed due to a large amount of missing data. Statistical significance was set a priori at $p < 0.05$. Similar injuries were grouped together for analysis eg. Lumbar spine facet joint pain/stiffness (OSICS code: LGXX) and Lumbar muscle trigger points (OSICS code: LMYX) have a similar prognosis and management therefore they were grouped together for better representation of the data. Previous research have shown that clustering of injuries is accurate[28] and appropriate from an epidemiological approach.[29,30] Details of all combined OSICS code are described in Supplement 1.

A generalised estimating equation (GEE) was attempted for analysis of the HPQ data but given the high levels of missing data for the 3rd and 4th HPQ's, prevalence's across periods were used rather than introducing bias via unsubstantiated imputation methods for missing data. The 2nd HPQ data was manually matched to medical attention records from the tournament. Records that appeared in the HPQ and not in AMS were recorded and percentage of agreement was calculated as the percentage of records reported in both. All statistical analyses were performed in Stata (Stata/IC 15.1, StataCorp, USA).

3. Results

The data collected by team physiotherapists revealed a total of 103 medical attention injuries sustained by 80 athletes over a 6 day period at an incidence rate of 89.4 per 1000 player hours when 17/U and 19/U injuries were combined. There was significant missing data for athlete exposure, therefore overall exposure was calculated by multiplying the number of athletes (n = 12) by the number of teams (n = 16) by the number of matches (n = 9) by the number of minutes/match (n = 40). Sports incapacity incidence rate was 19.1 per 1000 player hours. The higher injury rate sustained by the 19/U age group was statistically significantly different (17/U, n = 39; 19/U, n = 64; IRR 1.64 95%CI 1.08–2.51). Lateral ankle ligament sprain (AJLX/AJLA, n = 14, 13.6%), foot blisters (FKBX, n = 11, 10.7%), and lumbar pain (LGXX/LMYX, n = 10, 9.7%) recorded the highest incidence across medical attention injuries in both age groups. There were 22 (21% of total injuries) sports incapacity injuries with ankle sprain (AJLX/AJLA, n = 4), anterior cruciate ligament (ACL) rupture (KJAX, n = 3) and concussion (HNCO, n = 3) recorded as the highest sports incapacity injuries. No statistical significant difference was observed between age group with respect to sport-incapacity injury incidence (17/U, n = 9, 8.7%; 19/U, n = 13 12.6%; IRR 0.69 95%CI 0.26–1.75).

New injuries occurred nine times more frequently than recurrent injuries (IRR 9.3 95%CI 4.84–20.03, $P < 0.001$). There were more traumatic injuries than overuse injuries (trauma n = 51, overuse n = 42; IRR 1.24 95%CI 0.62–2.49, P = 0.522). The body region most commonly injured was the lower limb ($\chi^2_3 = 91.45$, $p < 0.001$) and joint injuries accounted for nearly one third of all injuries ($\chi^2_5 = 30.69$, $p < 0.001$) (Supplement 2). Daily prevalence rates could not be calculated due to a significant amount of missing exposure data (31%). Details of mechanism of injury, new v recurrent and trauma v overuse according to each body area are outlined in Table 1.

The response rate declined across the four HPQ's (1st 90%; 2nd 76%; 3rd 41%; 4th 34%). The HPQ revealed that 46 (27.2%) athletes arrived at the tournament with an existing self-reported injury/illness and 57 (39.3%) athletes had a self-reported injury/illness at the conclusion of the ANNC (RR 1.44 95%CI 1.05–1.99, p = 0.030). Twenty-two (34%) athletes were training at a reduced volume 4/52 post nationals due to self-reported injury/illness. Fifty-five (38%) athletes thought their performance was affected by injury/illness during the tournament (Fig. 2). Less 17/U athletes (n = 64, 66.7%) sought medical professionals for their health problems compared to 19/U athletes (n = 68, 74.7%). There was an increase of moderate severity self-reported injuries in the 19/U group, 4/52 post tournament. The period prevalence of self-reported health problems for the 17/U athletes and 19/U athletes was 55% (n = 53, 95%CI 45–65%). According to the HPQ data, the 19/U athletes had slightly less substantial health problems (n = 29, 30%; 95%CI 21–40%) compared to the 17/U athletes (n = 30, 31%; 95%CI 22–42%).

Seventy tournament self-reported injuries/illnesses were identified by the post-tournament HPQ. Twenty-six percent (n = 18) of these injuries were not recorded in AMS. Twelve of the missing records were overuse injuries and ten were illnesses.

4. Discussion

This study recorded 103 medical attention injuries sustained by 80 athletes during the ANNC's. We observed higher medical attention injury rates in 19/U athletes compared to 17/U athletes however the distribution of injury types was similar across both age groups and the HPQ revealed equal self-reported injury/illness period prevalence during the tournament in the 17/U and 19/U age groups (n = 53, 55%, 95%CI 45–65%). The main sports incapacity injuries recorded were ankle sprains, ACL rupture and concussion.

In the past 30 years only three studies[2,4,5] have specifically reported injury rates at tournaments for development netball athletes. The most recent study reporting injury rates at a pre-elite netball tournament conducted a decade ago in South Africa, reporting a medical attention injury incidence rate of 500.7 per 1000 player hours.[5] However, their definition of exposure was only the game time a player participated before the injury occurred rather than total exposure, resulting in a higher injury incidence rate. Hume and Steel (2000)[4] reported a medical attention injury rate of 23.8 per 1000 player hours at a state netball tournament was conducted over 20 years ago and the athletes were at a T2 and T3 FTEM level rather than the pre-elite (T3-4) level. The difference in injury rate could possibly be due to the difference in FTEM level. Our study revealed a medical attention injury incidence rate of 89.4 per 1000 player hours when 17/U and 19/U injuries were combined. This is the first publication in a decade to report tournament injury rates for pre-elite netball athletes and fulfils the first stage of the TRIPP[17] framework for sports injury prevention.

We observed the 19/U athletes had a higher medical attention incidence (IRR 1.64). This indicates that 19/U athletes sustained 64% more medical attention injuries compared to the 17/U athletes. However, whilst there was a difference in medical attention incidence between age groups there was no difference between the 17/U and 19/U athletes in terms of sports incapacity, body region injured, nature of injury, new versus recurrent, trauma versus overuse and mechanism of injury as demonstrated by incidence rate ratios and risk ratios. Interestingly, the HPQ identified equal number of injuries/illnesses in the 17/U & 19/U age group. This may just suggest that 19/U athletes were more likely to seek medical attention whereas the younger athletes did not. Future research should explore why the two year age difference results in apparently different medical attention injury rates.

The most frequently recorded medical attention injury diagnoses across both age groups were lateral ankle ligament sprain, foot blisters, and lumbar pain. There were 22 (21% of total injuries) sports incapacity injuries, 41% of these were ankle and foot injuries and 18% were knee injuries. Knee injuries in netball have attracted media attention and thought to be the most common injury which there is some evidence for[31,32] however these claims are based on hospital admission data. Most netball injuries are managed without hospital admission therefore this research is not a true reflection of injury rates in netball. The vast majority of netball

Table 1
Mechanism of injury, new v recurrent & trauma v overuse for each body area.

	Body area										
	Ankle	Foot	Trunk[a]	Lower leg	Head & Neck	Knee	Wrist & Hand	Pelvic area[b]	Shoulder	Thigh	Total
Total (n=)	26	19	17	10	6	6	6	5	5	3	103
Mechanism of injury											
Accident/other	0	2	0	0	0	0	0	0	1	1	4
Catching	0	0	0	0	0	0	4	0	1	0	5
Change of direction	4	0	0	0	0	1	0	0	0	1	6
Collision	2	0	1	4	4	0	1	2	2	1	17
Contested landing	7	0	1	0	1	3	0	0	1	0	13
Jumping	2	1	0	0	0	0	0	0	0	0	3
Land on another	2	1	0	0	0	0	0	0	0	0	3
Non-contested landing	1	0	1	0	0	0	0	0	0	0	2
Running	1	8	1	5	0	0	0	1	0	0	16
Throw/Passing	0	0	0	0	0	1	1	0	0	0	2
Unknown/missing	7	7	13	1	1	1	0	2	0	0	32
New v recurrent											
New injury	25	16	16	8	4	6	6	4	5	3	93
Recurrent injury	1	3	2	0	2	1	0	0	1	0	10
Trauma v overuse											
Trauma	18	2	2	4	5	5	6	2	4	3	51
Overuse	7	15	11	4	0	1	0	3	1	0	42
Other	1	2	4	2	1	0	0	0	0	0	10

[a] Thoracic spine, Chest and Lumbar spine.
[b] Buttock, pelvis, hip and groin.

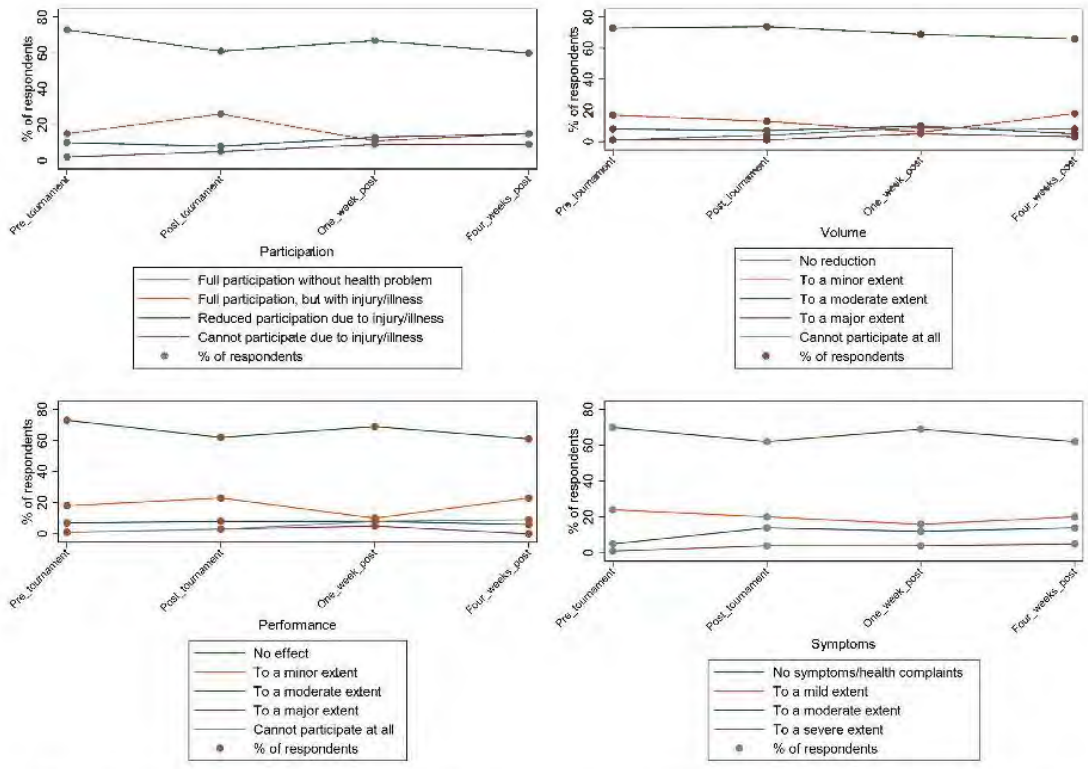

Fig. 2. HPQ results across time for participation (top left), volume (top right), performance (bottom left) and symptoms (bottom right).

epidemiology data has reported ankle sprains to be the most common.[2,3,5] It is difficult to determine the most common mechanism of injury for the most frequent injuries because as outlined in Table 1 'unknown/missing' data was twice as high as the next most common mechanism 'collision'. Foot blisters can be easily prevented with correct footwear and foot hygiene. The cause of ankle sprains, low back pain, ACL rupture and concussion require further investigation to inform future preventative strategies. Additional strategies to reduce the problem of 'unknown/missing' data could be (1) making AMS data entry fields compulsory to increase data collection for 'contributing factors' or (2) utilising match video footage to record such information.

ACL rupture at the ANNC's is not common. We found three ACL ruptures in a population of 192 athletes resulting in a period prevalence rate of 1.6% chance of rupturing an ACL at the ANNC. This is similar to the 1.8% overall incidence rate reported between

1985 and 1989.[18] It has been demonstrated that minor injuries are often precursors to more significant injuries,[33–35] perhaps the best strategy for preventing these more significant, but less common injuries is by preventing the precursor injury such as ankle sprain. Injuries to one bodily area have been shown to precede injuries to another area within the same person.[33] With recent evidence in Kayak,[36] Rugby Sevens,[30] Australian Football[35] demonstrating this non-causal association. Non-time-loss injuries have been shown to precede time-loss injuries in Australian Football with survival rates (of not incurring a time loss injury) being approximately 50% within the 12 weeks following a lower limb muscle injury.[35] Of the three ACL injuries, one athlete developed foot blisters and hip pain at the ANNC prior to their ACL injury. We're not inferring direct causation but we are suggesting that future ACL epidemiology studies need to record minor injuries or aetiological factors that may result in early detection preventative strategies.

Due to discrepancies in reporting, multiple tools are required for quality injury surveillance. The HPQ identified twenty-six injuries/illnesses that were not recorded in AMS, 12 of these were overuse injuries and ten were illnesses. The AMS recorded 33 injuries not identified in HPQ. The HPQ was developed as a way of capturing overuse injury data that is not captured when a 'medical attention' injury definition is used throughout the tournament. The HPQ is also useful for capturing illnesses when physiotherapists are the sole health professional and recording medical attention data as their scope of practice excludes them from diagnosing illnesses in Australia. Using a dual injury/illness capture system may be preferable in this setting to ensure all injury/illness records are captured, resulting in improved injury prevention interventions.

Many netball athletes are starting the ANNC's with injury or illness. Twenty-seven percent of athletes arrived at the tournament with an existing injury/illness. This replicated the finding for U/21 and U/16 netball athletes competing at the 1988 Australian netball championships.[2] This prevalence has not changed in 30 years and considering that many injury prevention interventions have been trialled over this period suggests that developing effective implementation strategies are still important.[17] A recent systematic review investigating injury prevention strategies in pre-elite athletes has shown that implementation planning does not routinely occur in sport despite it being a key stage of the TRIPP framework.[37]

A limitation of this research is the varied response rate occurring across the four times the HPQ was administered. While response rates decreased over the tournament, the first and second questionnaire response rates, 88% and 76% respectively, enable robust conclusions to be made.[38] We attempted to analyse the data using all responses across the tournament however the missing data limits analysis. To ensure that we didn't introduce potential bias we did not utilise imputation methods as reported in similar research.[20] Future research can improve through targeting compliance of the netballers in completing all questionnaires issued over the championship period.

5. Conclusion

There are no recent studies reporting injury rates specifically in pre-elite netball players. This study found an IRR of 89.4/1000 player hours when 17/U and 19/U injuries were combined. Ankle sprains are the highest medical attention and sports-incapacity injury in pre-elite netball athletes. Foot blisters and low back pain also feature in the highest medical attention injuries at the ANNC's. Finally, combining both the medical attention (AMS) and self-report (HPQ) injury data collection methods optimises injury surveillance. Injury prevention efforts for pre-elite netballers should focus on ankle sprains for best effect.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.jsams.2019.10.004.

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Unpublished data from the 2018 17/U & 19/U ANNC

Of the 103 medical attention injuries that occurred at the 2018 17/U & 19/U ANNC, the team physiotherapist did not ask about menstrual cycle 37 times (36%) or the data were missing for 18 (17%) injury records (Figure 8). Therefore, over half (53%) of the menstrual cycle data were missing and inference about injury/illness aetiology cannot be made.

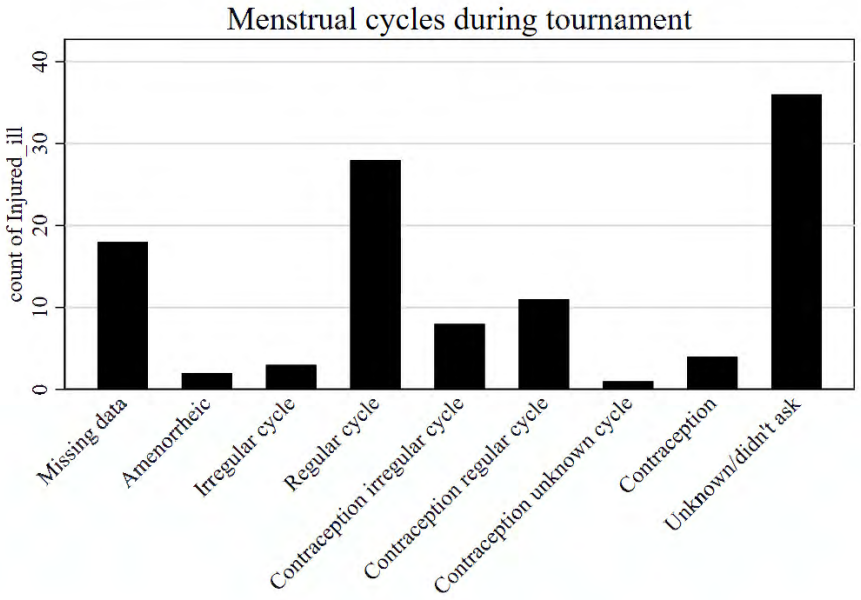

Figure 8: Menstrual cycle data collected by team physiotherapists

There were 22 sports incapacity injuries recorded by team physiotherapists across the six-day 2018 17/U & 19/U ANNC. Following ankle sprain, ACL rupture and concussion, foot blisters and foot sprain were the next most frequent sports incapacity injuries (Table 1).

Table 1: Sports incapacity injuries at the 2018 17/U 7 19/U ANNC

Diagnosis	Sports incapacity (n=)
Ankle sprain	5
ACL rupture	3
Concussion	3
Foot blister	2
Foot sprain	2
Thigh strain	1
Thoracic pain	1
Lumbar pain	1
Calf tightness	1
Shoulder subluxation	1
Pec strain	1
Shin pain	1
Total	22

Chapter 3 Developing preventative measure (TRIPP 3)

Published work

This chapter is based on a manuscript that has been published in the Journal of Science and Medicine in Sport.

> **Smyth E**, Newman P, Waddington G, et al. Injury prevention strategies specific to pre-elite athletes competing in Olympic and professional sports – a systematic review. *J Sci Med Sport*. 2019; 22:887-901.

Chapter 2 reported the injury rates for pre-elite netball athletes. The most frequently recorded medical attention injury diagnoses across both the age groups were lateral ankle ligament sprain (n=14, 13.6%), foot blisters (n=11, 10.7%), and lumbar pain (n=10, 9.7%). Ankle sprains (n=4), ACL ruptures (n=3) and concussion (n=3) were recorded as being the highest sports incapacity injuries. The self-report data collection revealed that 46 (27.2%) athletes arrived at the tournament with an existing self-reported injury/illness and 57 (39.3%) athletes had a self-reported injury/illness at the conclusion of the ANNC (RR 1.44 95%, CI 1.05–1.99, p=0.030). New injuries occurred nine times more frequently than recurrent injuries (IRR 9.3 95%, CI 4.84–20.03, p<0.001). There was no significant difference between the overall number of traumatic (n=51) and overuse (n=42) injuries sustained in the tournament (IRR 1.24 95%, CI 0.62–2.49, p=0.522). It is difficult to determine the most common mechanism of injury for the most frequent injuries because, as outlined in Table 1, 'unknown/missing' data was twice as high as the next most common mechanism, 'collision'. These results are similar to Hume & Steele[58] and highlights the need to prioritise mechanism of injury data collection. Perhaps reviewing match play video would result in more accurate data collection.

Following injury surveillance and establishment of aetiology and mechanism of injury, the next step is to develop a preventative measure for the priority injuries. The Intervention Development Process (IDP) has been created to guide intervention development in the sporting environment.[67] The first IDP step is to 'use the research evidence and clinical experience'; therefore, the following systematic review helps

inform TRIPP Stage 3 (develop preventive measure). A review of injury prevention strategies has not previously been conducted specifically for pre-elite athletes.

Co-authors' declaration

Declaration of Co-Authored Publications

UNIVERSITY OF CANBERRA

For use in theses which include co-authored publications. This declaration must be completed for each co-authored publication and to be placed at the start of the thesis chapter in which the publication appears, or as a preface to the thesis.

Declaration for Thesis Chapter Three

Publication: "Injury prevention strategies specific to pre-elite athletes competing in Olympic and professional sports - A systematic review"

DECLARATION BY CANDIDATE

In the case of Chapter Four, the nature and extent of my contribution to the work was the following:

Nature of Contribution	Extent of Contributions (%)
Conception and design of the review	70%
Development and application of search strategy and selection criteria	50%
Completion of risk of bias assessment	50%
Extraction, analysis and interpretation of data	50%
Writing the paper and critical appraisal of content	70%
Corresponding author for journal communication and publication peer-review process.	100%

The following co-authors contributed to the work:

Name	Nature of Contribution	Contributor is also a UC student (Yes/No)
Gordon Waddington	Conception and design of the review Writing the paper and critical appraisal of content	No
Phil Newman	Extraction, analysis and interpretation of data Writing the paper and critical appraisal of content	No
Juanita Weissensteiner	Writing the paper and critical appraisal of content	No
Michael Drew	Conception and design of the research proposal Extraction, analysis and interpretation of data Completion of risk of bias assessment Writing the paper and critical appraisal of content	No

_____ ___17/09/2021_____

Candidate's Signature Date

DECLARATION BY CO-AUTHORS

The undersigned hereby certify that:

(1) the above declaration correctly reflects the nature and extent of the candidate's contribution to this work, and the nature of the contribution of each of the co-authors.

(2) they meet the criteria for authorship in that they have participated in the conception, execution, or interpretation, of at least that part of the publication in their field of expertise;

Declaration of Co-Authored Publications

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(3) they take public responsibility for their part of the publication, except for the responsible author who accepts overall responsibility for the publication;
(4) there are no other authors of the publication according to these criteria;
(5) potential conflicts of interest have been disclosed to (a) granting bodies, (b) the editor or publisher of journals or other publications, and (c) the head of the responsible academic unit; and
(6) the original data are stored at the following location(s) and will be held for at least five years from the date indicated below:

[Please note that the location(s) must be institutional in nature, and should be indicated here as a department, centre or institute, with specific campus identification where relevant.]

Location(s):	Australian Institute of Sport

Phil Newman
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Gordon Waddington
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Juanita Weissensteiner
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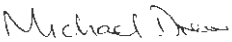
Michael Drew
Signed: 
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Review

Injury prevention strategies specific to pre-elite athletes competing in Olympic and professional sports — A systematic review

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ABSTRACT

Objectives: To describe and evaluate injury prevention interventions for pre-elite athletes who compete in an Olympic or professional sport.
Design: Systematic review.
Methods: This review was prospectively registered (PROSPERO CRD42017065083) and a systematic electronic search was conducted in May 2017. The following inclusion criteria were applied: (1) studies including and analysing data specific to pre-elite athletes (determined by the T3/T4 levels of the FTEM model); (2) featured injury prevention interventions; (3) provided sufficient data related to injury such that the effect can be analysed e.g. injury rates, incidence, prevalence, injury rate ratios; (4) featured randomised and non-randomised controlled trials or prospective cohorts.
Results: A total of 13,480 articles were retrieved with 121 titles identified and 11 studies satisfying the inclusion criteria. No studies demonstrated a low risk of bias. Four different interventions were identified: exercise (n = 7, 64%), psychological (n = 2, 18%), equipment (n = 1, 9%), nutrition (n = 1, 9%). Of the seven exercise interventions, four showed a protective effect and three found no significant effect, providing conflicting evidence. Caution is advised due to high risk of bias, low intervention reporting and minimal evidence for implementation planning in all seven studies.
Conclusions: There is limited evidence from level 2 and 3 studies suggesting exercise and psychology interventions may prevent injury in pre-elite athletes. There is an absence of evidence to support the use of equipment and nutrition interventions in pre-elite athletes. There is a need for quality research designs confirming the clinical impact of existing injury prevention interventions for pre-elite athletes.

1. Introduction

Injuries reduce the chance of successful performance and progression by sportspeople.[1] There is a plethora of injury prevention research for adult, youth and elite athletes.[2–4] To date, there has not been a systematic review of intervention studies for injury prevention in pre-elite athletes who compete in an Olympic or professional sport. Pre-elite athletes, as defined by the FTEM Athlete Development framework[5] (Foundation, Talent, Elite and Mastery) are 'Talent' level athletes (i.e., Talent 1–4) that are commonly emerging from the junior ranks and who have been formally recognised as having future high performance potential by their respective state or national level sporting organisation, state academy or institute, university or professional club and receive limited financial and service support but sit below a senior elite level. Recognised by the International Olympic Committee's recent consensus statement on youth athlete development,[6] the FTEM framework is utilised extensively within Australia, Japan and Switzerland to review and refine strategy, practice and support specific to the sports pathway considerate of its foundational, pre-elite (talent) and elite components.

At a T1 level, an athlete demonstrates their initial potential through formal and informal talent identification processes. At a T2 level an athlete's holistic talent potential is confirmed by immersing them into realistic training and competitive contexts. Following

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this level, an athlete is then embedded into a dedicated developmental period where they are provided with quality coaching, daily training environments, education, service support and competition exposure. Transition to the final talent level T4, signals that the athlete has achieved a breakthrough performance and that they are soon ready to progress to a senior elite level in their chosen sport (i.e., E1 level). A podium performance in the highest levels of elite competition equates to an E2 (Elite 2) level and multiple podium achievement at this level an M (Mastery) level. Specific to the pre-elite athlete population (i.e., FTEM T levels) it is well recognised that the onset of puberty and rate of biological maturation can vary greatly between athletes within and across sports.[7] This variation in maturation and often an increase in workload, insufficient recovery and lack of support services creates a challenging environment for coaches to develop their athletes while keeping them injury and illness free.[6] Previous injury predisposes an athlete to further injuries of the same nature[8] or a different site and nature.[9] To prevent injuries in elite and professional athletes, it is plausible that preventive activities should commence at the pre-elite level. Preventing the index injury (the first injury) will potentially increase the long term health of athletes as well as maximising the pool of athletes eligible to compete at an elite and professional setting. This premise is supported by the work of Huxley et al.[10] demonstrating that 17.3% of injured pre-elite track and field athletes retire due to injury prior to turning eighteen years of age.

This systematic review will inform practitioners working with pre-elite athlete populations in three ways:

- Describe and assess injury prevention interventions trialled in pre-elite populations.
- Synthesise the available evidence on injury prevention strategies used in pre-elite athletes.
- Provide future directions and opportunities for future research in pre-elite injury prevention

2. Methods

The Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) guidelines[11] were followed and the protocol was registered on the PROSPERO International prospective register for systematic reviews website (http://www.crd.york.ac.uk/PROSPERO) on 9 May 2017, with the following registration number: CRD42017065083.

The inclusion criteria were: (1) studies that separately analysed pre-elite athletes who are formally recognised and supported by their respective National Sporting Organisation or professional club as having future high performance potential who compete in Olympic and professional sports; (2) injury prevention intervention specific to pre-elite athletes (as determiend by the T3 and T4 levels of the FTEM model) competing in Olympic and professional sports; (3) studies provide sufficient data related to injury such that the effect can be analysed, e.g. injury rates, incidence, prevalence, injury rates ratios; (4) study design of randomised controlled trial, prospective cohort studies and non-randomised controlled trials. Exclusion criteria were: (1) elite athletes e.g. athletes who compete in an Olympic sport and represent their country at key international events including the Olympics, World Championships etc. (2) Professional athletes e.g. elite athletes who compete at the highest professional level in their sport nationally (e.g. Australian Football League for Australian Football) and/or internationally (e.g. ATP World Tour in tennis). (3) Recreational athletes that are not formally recognised and supported as emerging pre-elite athletes by their respective national sporting organisation; (4) study designs of case reports, case series and any cross-sectional designs.

A comprehensive electronic search of the literature in MEDLINE, CINAHL, PubMed, SportDISCUS and Web of Science was conducted on 23 May 2017 with a date restriction of 2000 onwards and only English language as a limitation. Details of the PubMed search strategy is included as a supplement. All potential references were imported into Endnote X7 (Thompson Reuters, Carlsbad, California, USA) and then into Covidence (Covidence systematic review software, Veritas Health Innovation, Melbourne, Australia. Available at www.covidence.org) and duplicates removed. Titles and abstracts were independently screened for eligibility by two authors (ES and PN). The full text of each included study was then independently examined according to the inclusion and exclusion criteria, and reference lists of included studies were manually searched to find any further articles for inclusion. In the event of disagreement between authors, additional authors (GW and JW) were consulted to reach consensus.

Data from included studies were extracted and collated by one reviewer (ES) and confirmed by another (MD). The following data were extracted and collated: (1) demographics, FTEM level[12], outcome measures, working injury definition, injury definitions concept framework (IDCF)[13] (2) study design, data collection period, statistical analysis, effectiveness, level of strength, level of evidence (OCEBM)[14] (3) intervention summary, co-intervention, reproducibility and intervention reporting standard.

Where person-time exposures were not explicitly reported we documented the number of athletes in each group and assumed the intervention time in each group was identical. The key outcomes were presented in a forest plot using incidence rate ratio (IRR) as the comparator. Incidence rates reported in each study were used to calculate the IRR, where incidence rates were not presented they were determined by using raw data.

Intervention Mapping facilitates effective health promotion program planning, implementation and evaluation. IM (Step 5) can be used independently of other IM steps and focuses on planning program adoption, implementation and maintenance.[15] This practical implementation planning protocol has been previously used in a sporting environment with good effect.[16] Each included article was mapped according to IM (Step 5) to determine the risk of bias in implementation. To be judged as low risk of bias the authors needed to explicitly state who the adopters, implementers and planners were as well as outline the implementation performance & change objectives, determinants, strategies and design. A judgement of unsure was given when some information was provided with insufficient detail. A high risk of bias was recorded when no detail was provided for that task.

Two reviewers (ES and MD) independently conducted a risk of bias assessment on each selected article using the Cochrane Collaboration's tool for assessing the risk of bias in randomised trials.[17] If at least one of the criteria was rated as high, the trial was considered to have a high risk of bias. To be considered as a low risk of bias, all criteria had to be rated low risk. Any trials not meeting these criteria were rated unclear.

The level of evidence of interventions for the prevention of injury in the pre-elite athlete was evaluated using previously published guidelines.[18] The level of evidence was defined as strong: provided by two or more studies with a low risk of bias and by generally consistent findings in all studies (>75% of the studies reported consistent findings); moderate: provided by one study with a low risk of bias and/or two or more studies with a high risk of bias, and by generally consistent findings in all studies(>75% of the studies reported consistent findings); limited: provided by only one study with a high risk of bias; conflicting: inconsistent findings among multiple trials (>75% of the studies reported consistent findings).[18]

The Oxford Centre of Evidence-based Medicine (OCEBM) — Levels of Evidence was used to determine the hierarchical levels of evidence according to the type of research question with the highest level of evidence. The highest level (Level 1) is a systematic

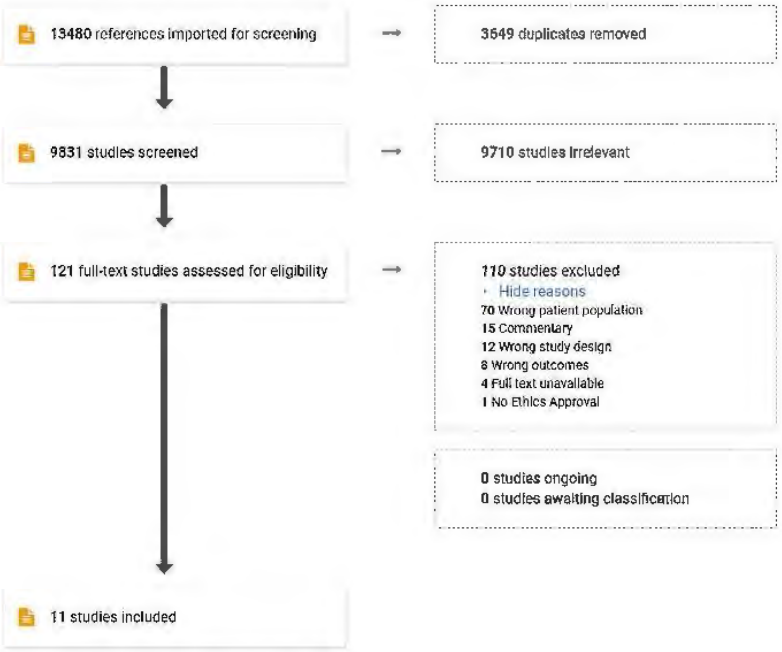


Fig. 1. PRISMA flow chart, PRISMA: Preferred Reporting Items for Systematic Reviews and Meta-Analyses.

review with specific criteria, and the lowest level (Level 5) is 'mechanism-based reasoning'.[14]

The IDCF classification was used to assist with injury definition. It is a system for categorising injuries and illnesses according to clinical examination (injury or disease), athlete self-report (trauma or illness) and/or sports performance (incapacity or sickness).[13] This is a classification system derived from World Health Organisation's (WHO) framework: International Classification of Functioning, Disability and Health (ICF) but adapted for sport impairment.[19]

The reporting standard of exercise intervention was assessed using the Consensus on Exercise Reporting Template (CERT): explanation and elaboration statement.[20] This template has been designed to evaluate the reporting of exercise programmes across all study designs used in exercise research. It has previously been utilised in similar studies where the authors used the following criteria: studies satisfying >75% of criteria were considered to have a high level of reporting standard; 60–74% moderate; and those satisfying less than 60% of criteria were considered to have poor exercise reporting standards.[2]

The 'Workgroup for Intervention Development and Evaluation Research' (WIDER) recommendations provide a framework to identify and provide detailed reporting of the essential components of behaviour change interventions in order to facilitate replication, further development, and progression of the interventions.[21] This 20-item checklist was used to evaluate the standard of reporting for any psychological interventions. The following criteria were applied: studies satisfying >75% of criteria were considered to have a high level of reporting standard; 60–74% moderate; and those satisfying less than 60% of criteria were considered to have met minimal reporting standards.[2]

Results of randomised controlled trials were considered eligible for meta-analysis if all the following criteria were met: (1) athlete populations were similar or comparable; (2) the same outcome measures were reported (3) studies demonstrated a low risk of bias. Where three or more studies examined the same intervention using an equivalent summary statistic, a meta-analysis was considered.[22]

In the circumstances where it was not appropriate to pool the results due to clinical heterogeneity (varying athlete population, outcome measure, high risk of bias), the results were ordered systematically via a forest plot without summary estimates as recommended in the PRISMA statement.[22] The results were grouped according the type of injury prevention intervention or strategy utilised in the study.

3. Results

The electronic search identified 13,480 records; duplicates were then removed resulting in 9831 articles. The titles and abstracts were screened which reduced the number of articles to 121. The full texts of these articles were obtained and assessed for eligibility against the inclusion criteria. No articles were added following citation checking. One hundred and ten studies were excluded due to not meeting the required inclusion criteria. The two most common reasons for exclusion were (1) the patient population was not deemed to be of a pre-elite level (n = 70) and 2) the study did not feature an intervention (n = 27). The remaining eleven articles were included for full review and data synthesis.[23–33] A third author (JW) was consulted to reach consensus regarding study population. The flow chart of this process is presented in Fig. 1.

Table 1 presents the characteristics of the eleven studies including intervention type, participant characteristics, FTEM level, injury incidence rate & ratios, injury definition and injury definitions concept framework (IDCF). Study design, data collection period, statistical analysis, effectiveness, level of strength and level of evidence are provided in Table 2. A summary of the intervention is outlined in Table 3 as well as duration, frequency, compliance, specifics of intervention, co-intervention, reproducibility and reporting standards.

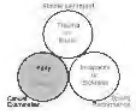
One article introduced new equipment as their injury prevention intervention,[23] seven studies looked at exercise as an injury

Table 1
Intervention, description of the study participants, level of competition, incidence of injury of included studies, injury definition and injury definitions concept framework (IDCF).

Intervention; article	Participants (male/female)	FTEM level, age (Age ± SD)	Injury incidence		IRR (95%CI)	Working injury definition	IDCF
			Intervention (exposure)	Control (exposure)			
Equipment							
Barbic et al.[23] Comparison of mouth guard designs and concussion prevention in contact sports.	Football (M) Rugby (M&F)	FTEM: T 3/4, Con: 20.9 ± 1.9	0.95/1000 athlete days (75 days × 308 = 23 256 athlete days)	0.90/1000 athlete days (75 days × 306 = 23 408 athlete days)	1.05 (.58–1.92)	As per American Academy of Neurology Concussion Guidelines	
	Canadian inter-university sport	Int: 20.8 ± 2.1	22/308 p'pants (22/23 256)	21/306 p'pants (21/23 408)			
Exercise							
Gilchrist et al.[24]	Soccer (F) NCAA Div 1	FTEM: 19.88	Total knee injury: 1.1/1000 AE	Total knee injury: 1.1/1000 AE	1.04 (0.95–1.13)	Injury to the area about the knee occurring in a game, practice or conditioning activity that required medical care by ATC or Physician, and caused one or more missed days of training	
A randomised controlled trial to prevent non-contact Anterior Cruciate Ligament injury in female collegiate soccer players			Practice ACL: 0.0/1000 AE	Practice ACL: 0.2/1000 AE	0.0		
			History of ACL, non-contact ACL: 0.0/1000 AE	History of ACL, non-contact ACL: 0.1/1000 AE	0.0		
			Late in season: 0.0/1000 AE	Late in season: 0.0/1000 AE	NC		
Junge et al.[27]	Soccer (M)	FTEM: T 3/4	High skill total injuries: 6.35/1000 h	High skill total injuries: 6.78/1000 h	0.94 (0.84–1.04)	Any physical complaint caused by soccer that lasted for more than 2 weeks or resulted in absence from a subsequent match or training session	
Prevention of soccer injuries: a prospective intervention study in youth amateur players	High skill (HS) & low skill (LS) teams	Con HS: 15.6 ± 0.86					
	Switzerland	Int HS: 16.2 ± 1.18					

Owoeye et al.[29]	Soccer (M)	FTEM: T 3/4	All injuries: 0.8/1000 h	All injuries: 1.5/1000 h	0.53 (0.23–1.26)	Injuries that resulted in players being unable to fully participate in subsequent football training sessions or matches	
Efficacy of the FIFA 11+ warm-up programme in male youth football.	Premier league, Lagos junior league	Con: 17.80 ± 0.94	Overuse injuries: 0.0/1000 h	Overuse injuries: 0.2/1000 h	0.0		
		Int: 17.49 ± 1.10	Acute injuries: 0.9/1000 h Mild injuries: 0.2/1000 h	Acute injuries: 1.3/1000 h Mild injuries: 0.4/1000 h	0.69 (0.26–1.75) 0.5 (0.06–1.81)		
Scase et al.[30]	Aus Football (M)	FTEM: T3	All injuries: 26.33/1000 h	All injuries: 38.51/1000 h	0.69 (0.66–0.73)	Any incident occurring during a football game or training session that resulted in a player missing one or more elite competition games	
Teaching landing skills in elite junior Australian football: evaluation of an injury prevention strategy	Elite U18 National Football comp	Con: 17.0 ± 2.6					
		Int: 17 ± 2.5					
Silvers-Granelli et al.[32]	Soccer (M)	FTEM: T 3/4	Div 1 ACL's: 0.114/1000 AE	Div 1 ACL's: 0.317/1000 AE	0.36 (0.29–0.45)	No injury definition	No injury definition
Does the FIFA 11+ Injury prevention program reduce the incidence of ACL injury in male soccer players?	NCAA Div I and II	Con: 21 ± 1					
		Int: 20 ± 2					

Table 1 (*Continued*)

Intervention; article	Participants (male/female)	FTEM level, age (Age ± SD)	Injury incidence		IRR (95%CI)	Working injury definition	IDCF
			Intervention (exposure)	Control (exposure)			
Silvers-Granelli et al.[31]	Soccer (M)	FTEM: T 3/4	Div 1 Total injuries: 9.3/1000 AE (198/21248 AE)	Div 1 Total injuries: 16.05/1000 AE (355/22112 AE)	0.58 (0.49–0.69)	Any physical complaint sustained by a player that resulted from a football match or football training, irrespective of the need for medical attention or time loss from football.	
Efficacy of the FIFA 11+ injury Prevention Program in the Collegiate male soccer player	NCAA Div I and II	Con: 21 ± 1	Div 1 Game injuries: 18.83/1000 AE	Div 1 Game injuries: 29.36/1000 AE	0.64 (0.6–0.68)		
		Int: 20 ± 2	Div 1 Practice: 5.146/1000 AE	Div 1 Practice: 10.13/1000 AE	0.51 (0.49–0.53)		
Strength training reduces injury rate in elite young soccer players during one season	Tunisian player development program	13–14 yo					
Psychological							
Ivarsson et al.[25]	Soccer (M&F)	FTEM: T3	Total injuries: 7/21 p'pants	Total injuries: 12/20 p'pants	0.56 (0.46–0.67)	A condition that occurred as a result of participation in a soccer practice or game and resulted in 4 days or more of restricted or no practice including the day of injury	
It pays to pay attention: a mindfulness based program for injury prevention with soccer players	Swedish junior elite	16.97 ± 0.79	181 days (7/3801)	181 days (12/3620)			
			1.84/1000 athlete days	3.31/1000 athlete days			
Johnson at al.[26]	Soccer (M&F)	FTEM:	Total injuries: 3/13 p'pants	Total injuries: 21/16 p'pants	0.18 (0.15–0.21)	Caused him or her to miss practice or competition, or to substantially modify participation for at least one day	
Injury prevention in Sweden: helping soccer players at risk	Swedish regional level teams	Male: 22.9	150 days (3/1950)	150 days (21/2400)			
		Female: 20.1	1.54/1000 athlete days	8.75/1000 athlete days			
Nutrition							
Lewis et al.[28]	Swimmers & Divers (M&F)	FTEM:	Total injuries: 9/19 p'pants	Total injuries: 4/13 p'pants	1.54 (1.27–1.87)	Bone, connective tissue and muscle injury not caused by acute trauma	
The effects of season-long Vitamin D supplementation on collegiate swimmers and divers	NCAA Div I	Con: 19 ± 1.1	182 days (9/3458)	182 days (4/2366)			
		Int: 19 ± 1.6	2.60/1000 athlete days	1.69/1000 athlete days			

FTEM: foundation, talent, elite, mastery framework, IRR: incidence rate ratio, IDCF: injury definitions concept framework, FIFA: Fédération Internationale de Football Association, NCAA: The National Collegiate Athletic Association, AE: athlete exposure, ACL: anterior cruciate ligament.

Table 2
Characteristics of the studies including data collection period, statistical analysis, efficacy, level of evidence.

Intervention; article	Study design	Data collection period	Statistical analysis	Effectiveness/level of strength for intervention type	Level of evidence (OCEBM level)
Equipment					
Barbic et al.[23]	Randomised controlled trial	September 3–November 17, 2003	Intention-to-treat analysis	X	Level 2
Comparison of mouth guard designs and concussion prevention in contact sports.			Injury rates between groups were compared using a P value and odds ratio	Level of strength: Limited	
Exercise					
Gilchrist et al.[24]	Randomised controlled trial	Fall 2002 NCAA season	Z statistic for rate ratios.	✓	Level 2
A randomised controlled trial to prevent non contact Anterior Cruciate Ligament injury in female collegiate soccer players			As-treated analysis		
Junge et al.[27]	Prospective controlled intervention study	Two seasons of Swiss football: 1999 & 2000	Incidences of injury compared by calculating z-values.	High-skill:	Level 3
Prevention of soccer injuries: a prospective intervention study in youth amateur players			Differences between groups examined using t-tests.	X	
Owoeye et al.[29]	Cluster randomised controlled trial	Six months: 2012/2013 season	Intention to treat principles.	X	Level 2
Efficacy of the FIFA 11+ warm-up programme in male youth football.			Injury rate ratios calculated using Poisson regression analysis		
Scase et al.[30]	Prospective non-randomised controlled trial	U18 Australian football.	Injury incidence.	✓	Level 3
Teaching landing skills in elite junior Australian football: evaluation of an injury prevention strategy		2 seasons: 2002/2003	Independent tests/Mann–Whitney U test used for comparison.		
			Cox proportional hazards regression. Relative risk and 95% CI		
Silvers-Granelli et al.[32]	Prospective cluster randomised controlled trial	August–December 2012	Frequency counts, t-tests, chi-square tests, factorial analysis of variance, logistic regression tests. Injury rates.	✓	Level 2
Does the FIFA 11+ Injury prevention program reduce the incidence of ACL injury in male soccer players?					
Silvers-Granelli et al.[31]	Randomised controlled trial	August–December 2012	T tests, X^2 tests and generalised linear regression models	✓	Level 2
Efficacy of the FIFA 11+ injury Prevention Program in the Collegiate male soccer player					
Zouita et al.[33]	Randomised controlled trial	One soccer season. October to March	Mean ± SD. Kolmogorov–Smirnov tests. 2-way repeated-measures analysis of variance. Bonferroni post-hoc analysis. Chi-square test.	✓	Level 2
Strength training reduces injury rate in elite young soccer players during one season					
Psychological					
Ivarsson et al.[25]	Randomised controlled trial	August 2013–June 2014	Mann–Whitney U test.	X	Level 2
It pays to pay attention: a mindfulness based program for injury prevention with soccer players			Cohen's d effect size, 80% confidence interval		

Table 2 (*Continued*)

Intervention; article	Study design	Data collection period	Statistical analysis	Effectiveness/level of strength for intervention type	Level of evidence (OCEBM level)
Johnson et al.[26] Injury prevention in Sweden: helping soccer players at risk	Randomised controlled trial	January–June	Mann Whitney U test	✓ Level of strength: moderate	Level 2
Nutrition					
Lewis at al.[28] The effects of season-long Vitamin D supplementation on collegiate swimmers and divers	Randomised, placebo-controlled trial	August–March	Pearson correlations. Independent t tests. Linear regression model	X Level of strength: limited	Level 2

OCEBM: Oxford centre for evidence based medicine, FIFA: Fédération Internationale de Football Association, NCAA: The National Collegiate Athletic Association.

prevention intervention,[24,27,29–33] two examined the use of psychological interventions[25,26] and one was a nutrition intervention.[28] The equipment study found the 'WIPSS Brain-pad mouth guard' not to prevent concussions.[23] Five of the exercise interventions looked at whether a specific warm-up could prevent injuries in soccer/football players.[24,27,29,31,32] The other two exercise intervention programs provided training in developing landing, falling & recovery skills and strength training.[30,33] Mindfulness, acceptance & commitment approach was used in one of the psychological interventions,[25] and one-on-one psychology training was used in the other.[26] The nutrition study provided vitamin D supplementation as their injury prevention intervention.[28]

Eight of the eleven articles studied football players.[24–27,29,31–33] Five of these were conducted to help develop or assess the FIFA 11+ program developed by Fédération Internationale de Football Association (FIFA).[24,27,29,31,32] The remaining three investigations studied Canadian football and rugby players,[23] Australian football players[30] and swimmers & divers.[28]

The definitions and IDCF classification for each study are outlined in Table 1. A variety of injury definitions were used across the included studies with most studies using a sports incapacity (time loss) definition. According to the IDCF classification, seven of the studies definitions were based on sports performance,[25–27,29,30,33] two used clinical examination as their definition,[23,28] one study used a definition that included both sports performance and clinical examination,[24] one study used athlete self-report[31] and one study did not define injury.[32]

The risk of bias assessments are outlined in Fig. 2. Risk of bias assessment concluded that none of the included trials were low risk, ten (91%) were high risk, and one (9%) was unclear risk.[17] A major contributor to assessments of high risk of bias was lack of blinding and allocation concealment.

The level of strength according to guidelines previously published[18] and effectiveness based on IRR are outlined in Table 2. The strength of evidence was deemed to be moderate for exercise and psychological intervention and limited evidence for the use of equipment and nutrition interventions for injury prevention in pre-elite athletes. The hierarchical level of evidence was Level 2 for most of the intervention studies except for two which were Level 3 because they were non-randomised controlled trials.[27,30]

Outcomes with incident rate ratios are presented in Table 1. The use of a WIPSS Brain-pad mouth guard was shown to be ineffective for preventing concussion in 19–23 yo male and female Rugby and Football players.[23] The 'Prevent Injury and Enhance Performance' (PEP) program was trialled with 19 yo female soccer players. It was found to be ineffective for "all knee injuries" but was effective at reducing the number of ACL injuries sustained in practice and for reducing the number of non-contact ACL injuries in athletes who had previous ACL injury.[24] The Swiss study, using 15–17 yo male soccer players which was conducted as part of the FIFA 11+ development did not prove to be effective for the pre-elite portion of the population.[27] Of the three studies that implemented the FIFA 11+,[29,31,32] there were favourable outcomes for reduction of overuse injuries,[29] reduction of ACL injuries in pre-elite athletes,[32] reduction of total injuries, game injuries and practice injuries in pre-elite athletes.[31] These studies used 16–18 yo male soccer players[29] and 18–22 yo male soccer players.[31,32] Strength training in 13–14 yo male soccer players,[33] landing skills training in 15–19 yo male Australian Rules football players[30] and psychological training in 16–17 yo male and female soccer players[25,26] and 23 yo male and 20 yo female soccer players[26] were also shown to be effective. Vitamin D supplementation for 18-20yo male and female swimmers and divers was ineffective for injury prevention.[28] One of the FIFA 11+ studies reported a significant (IRR 0.59 95%CI 0.40–0.86) reduction in injuries for the intervention group but our calculations did not yield the same result (IRR 0.53 95%CI 0.23–1.26).[29] This is most likely due to a difference in statistical approach, Owoeye[29] et al. reported using Poisson regression analysis but we adopted a random-effects inverse-variance model.

Reporting standards were also assessed. It was not possible to identify a reporting standard for equipment and nutrition intervention studies. Consensus on Exercise Reporting Template (CERT) and Workgroup for Intervention Development and Evaluation Research (WIDER) scores were determined for exercise and psychological interventions respectively. Intervention details and reporting standard scores are displayed in Table 3. The CERT scores ranged from 26 to 74% for the exercise interventions. Five were deemed to be of poor standard [24,27,29,30,33] and two were to be of moderate standard.[31,32]

The WIDER scores were 30 and 65% for the psychology interventions. One was of poor standard,[26] and one was of moderate standard.[25] The article of poor standard gave no detailed information about the intervention content and no information regarding the control group.

There was no evidence of the use of IM (Step 5) to guide the implementation process for any of the included articles. Results are shown in Fig. 3. Adopters and implementers were identified in 45% (5/11) of the intervention studies.[24,26–28,33] Details of activities and resources used to improve reach, adoption and implementation of their injury prevention intervention programs were reported in

Table 3
Intervention summary, duration and frequency, specific details of intervention (ie reps, sets, intensity, progression), co-intervention, reproducible, intervention reporting standard.

Intervention; article	Intervention summary	Duration & frequency	Compliance levels	Specifics of intervention (reps, sets, intensity, progression)	Co-intervention	Reproducible	Intervention reporting standard (e.g. CERT)	
Equipment								
Barbic et al.[23] Comparison of mouth guard designs and concussion prevention in contact sports.	Use of WIPSS Brain-pad mouth guard	Not reported	Control: 73.8% (range by team, 68.1%–97.8%) I'vention: 69.6% (range by team, 68.4%–78.9%)	NA	Nil	Yes. WIPSS Brain pad available commercially	NA	NA
Exercise							CERT score (%)	Interpretation
Gilchrist et al.[24] A randomised controlled trial to prevent non contact Anterior Cruciate Ligament injury in female collegiate soccer players	Prevent injury and enhance performance (PEP) program. Stretching, strengthening, plyometrics, agilities and avoidance of high-risk positions.	12 weeks, 1–3/week	Average: 25.8 PEP sessions/team (2.15/week) Range: 12–37/team (1–3.1/week)	Warm-up movement (50 yards each) Strengthening: walking lunges (20yds × 2) Russian H-S's (3 × 10) Single toe raises (30reps/side) Stretching (30 s × 2) Plyometrics (20 reps each) Agilities (40 yards)	Nil	No. Web based program expired 19/10/17	7(37)	Poor
Junge et al.[27] Prevention of soccer injuries: a prospective intervention study in youth amateur players	F-MARC Bricks: Ankle & Knee stability Trunk, hip, leg strength & flexibility Co-ordination, reaction time & endurance	Not reported	Not reported	Not stated	Coach/player education/supervision; ankle taping, adequate rehabilitation, promotion of fair play	No. 'F-Marc Bricks' not clearly defined. Several interventions.	5(26)	Poor
Owoeye et al.[29] Efficacy of the FIFA 11+ warm-up programme in male youth football.	FIFA 11+	One season (25 weeks), 2/week	60% trainings (Range, 5–22 sessions/team) 1.6 times/week	Not stated	Nil	Yes. FIFA 11+ is well documented	7(37)	Poor

Table 3 (*Continued*)

Intervention; article	Intervention summary	Duration & frequency	Compliance levels	Specifics of intervention (reps, sets, intensity, progression)	Co-intervention	Reproducible	Intervention reporting standard (e.g. CERT)	
Scase, et al 2006. Teaching landing skills in elite junior Australian football: evaluation of an injury prevention strategy	Landing, falling & recovery skills: Prone fall, backward fall, sideways rolling, two foot landing, back shoulder roll	8 weeks, 1/week, 30 min sessions	Not reported	Not stated. Reference for intervention no longer available: http://www.kidskills.com.au	Aerobic endurance, weight training, skill acquisition	No. Specific program for training landing, falling and recovery skills not provided	6(32)	Poor
Silvers-Granelli et al.[32] Does the FIFA 11+ Injury prevention program reduce the incidence of ACL injury in male soccer players?	FIFA 11+: Dynamic warm-up: Strength, agility, proprioceptive and plyometric exercises	4 months, 2–3/week, 15–20 min	2.19 sessions/week Average: 32.78 ± 12.13 sessions/season	Details on website	Nil	Yes. Details of FIFA 11+ program can be found on provided website	12(63)	Moderate
Silvers-Granelli et al.[31] Efficacy of the FIFA 11+ injury Prevention Program in the Collegiate male soccer player	FIFA 11+: Dynamic warm-up: Running exercises (8 mins) – cutting, change of direction, decelerating, landing techniques; Strength, plyometric and balance exercises (10 mins); Running exercises (2 mins)	4 months, 3/week, 20 min	Average: 32.78 ± 12.13 sessions/season (2.19 sessions/week)	Details on website	Nil	Yes. Details of FIFA 11+ program can be found on provided website	14(74)	Moderate
Zouita et al.[33] Strength training reduces injury rate in elite young soccer players during one season	Progressive resistance training	12 weeks, 2–3/week, 90 min	Not reported	Individualised	4–5 soccer sessions/week 1 match/week	No. specific details of strength training, program not provided	6(32)	Poor

Psychological							WIDER score (%)	Interpretation
Ivarsson et al.[25]	'Mindfullness, acceptance and commitment approach' small group sessions	7 weeks, 1/week, 45 min	Not reported	Topics covered:	10–18 h soccer/week	No. specific details of MAC approach not provided	13(65)	Moderate
It pays to pay attention: A mindfulness based program for injury prevention with soccer players				Theoretical & practical aspects of intervention				
				Intro to mindfulness & cognitive defusion Intro to values & values-driven behaviours Intro to concept of acceptance Intro how to enhance commitment Intro how to combine mindfulness, acceptance & commitment in practice How to maintain & enhance mindfulness, acceptance & commitment				
Johnson, et al.[26]	One-on-one psychological training	20 weeks, 6 sessions and 2 phone calls	Not reported	Somatic & cognitive relaxation, stress management skills, goal setting skills, attribution & self-confidence training, identification & discussion about critical incidents	Not stated	No. details of psychological training not provided	6(30)	Poor
Injury prevention in Sweden: helping soccer players at risk		45–90 min						
Nutrition								
Lewis et al.[28]	4000 IU Vitamin D supplement	6 months, daily	Control: 76% (range, 64–87%)	NA	Nil	Yes. Specific details of Vitamin D supplement provided	NA	NA
The effects of season-long Vitamin D supplementation on collegiate swimmers and divers			I'vention: 70% (range, 29–88%)					

CERT: consensus on exercise reporting template, WIDER: workgroup for intervention development and evaluation research, FIFA: Fédération Internationale de Football Associati.

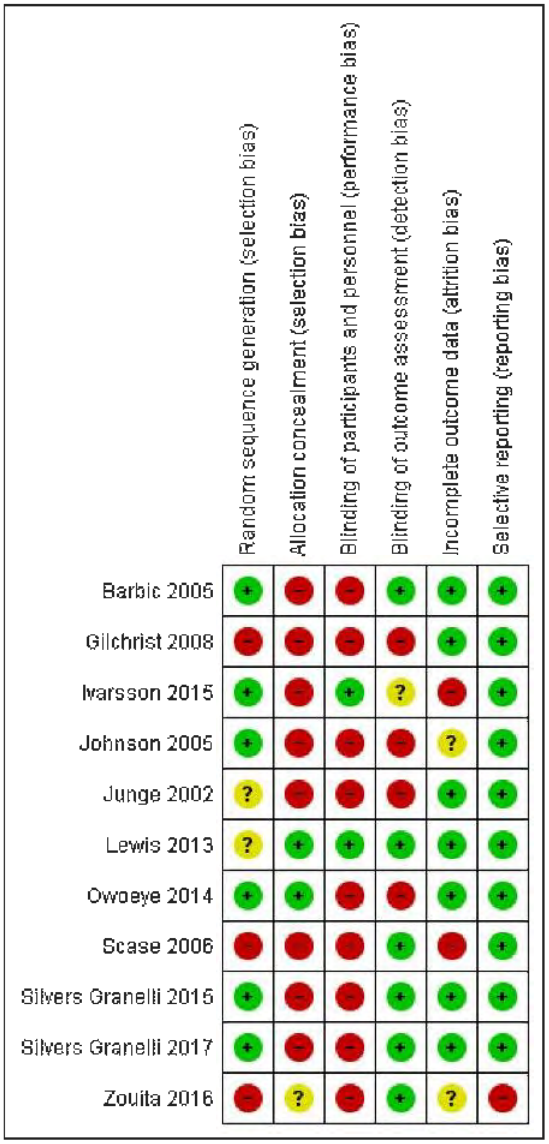


Fig. 2. Risk of bias summary (Please use colour).

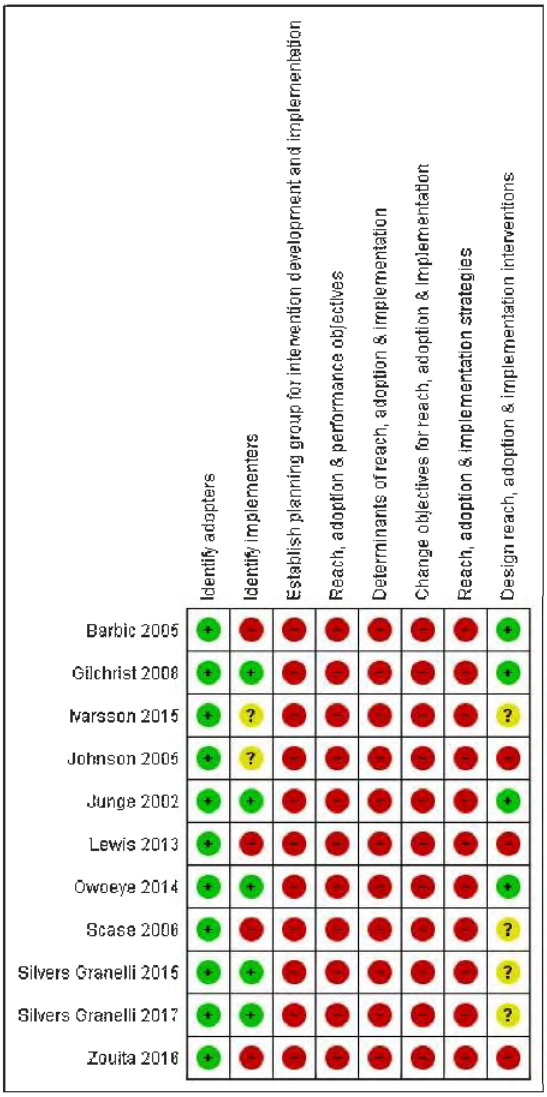


Fig. 3. Intervention Mapping (IM) Step 5 (Please use colour).

36% (4/11) of the included articles.[23,24,27,29] There was no evidence of tasks 3–6 of IM (Step 5) being utilised to assist with implementation planning.

A meta-analysis was not undertaken due to high risk of bias across all included studies. For the purpose of qualitative synthesis, the results were ordered systematically in a forest plot grouped according to intervention type Fig. 4.

4. Discussion

This systematic review highlights a lack of evidence-based strategies for injury prevention specific to pre-elite athletes. Exercise and psychological interventions have been shown to have efficacy in preventing injury in pre-elite athletes. However, a high proportion of these studies were shown to have a high risk of bias and poor reporting standards of the intervention.

Synthesised results indicate moderate strength of evidence for the efficacy of exercise interventions for the prevention of injury in pre-elite athletes. Three of the studies[29,31,32] assessed FIFA 11+, two were carried out in the USA College system,[31,32] and one was in Nigeria.[29] All three examined the effect of the FIFA 11+ warm-up on all injuries that resulted in players' absence from a match or training session. The American studies showed a 44% reduction in all Division 1 injuries and a 64% reduction in ACL injuries.[31,32] The Nigerian study reported a significant reduction in injuries but when we re-calculated IRR, the intervention was deemed to be ineffective.[29] While significant reductions were produced in some studies, there is still scope for greater injury reduction in the pre-elite environment. This could be achieved by improved implementation planning through the use of IM (Step 5). This will ensure the intervention is appropriate for the population and environment and strategies are employed to enhance reach, adoption and implementation.

There is a lack of evidence for the use of equipment to prevent injury in pre-elite athletes. However, we cannot dismiss the use of equipment for injury prevention because a previously published literature review identified over 600 studies in other athlete populations focussing on the use of equipment such as ankle braces and wrist guards which have been shown to prevent injury.[34–36] There is uncertainty whether these equipment interventions would also

menters have input from the very beginning and they have a strong contribution to the intervention development. Given the lack of reporting of consultation with end-users, it appears that all studies developed interventions and implementation strategies with little consultation with adopters and implementers and limited planning. Future studies should report any engagement with adopters and implementers to allow readers to understand the development process in full.

Adherence of participants to an intervention is vital as this will greatly influence the effectiveness of the intervention. Implementation and intervention planning is essential to maximise compliance. It is difficult to draw conclusions on effectiveness without knowing compliance levels. Five of the eleven studies did not report their compliance levels[25–27,30,33], three of these were exercise interventions[27,30,33] and two were psychology interventions.[25,26] The nutrition intervention[28] had a large range of compliance with the lowest level being 29%, perhaps this research should be repeated after undertaking the implementation mapping process in order to improve compliance and gain a true assessment of efficacy. Of the two exercise interventions that were shown to be ineffective, one did not report compliance[27] and the other reported sub-optimal compliance.[29]

The pre-elite athletic population's demographics can be wide ranging across sports. The age range of athletes in our included studies is 13–23 yo. This population can include pre-pubescent gymnasts and post-pubescent footballers. Nevertheless they can experience similar challenges such as a sudden increase in training load,[41] limited access to support services and a tendency for reduced recovery time due to other commitments such as school, university or work.[5,6] Perhaps addressing these extrinsic risk factors could be the most effective method for reducing injury in this athletic population.

There is evidence supporting the efficacy of exercise interventions in this population,[24,27,29–33] while there is a high risk of bias we need to understand it is very difficult to blind participants so this may be a case of misclassification. For those working in football there is evidence supporting the use of FIFA11+ in elite and community level,[42,43] however, our findings are purely focussed on pre-elite athletes. Additionally it must be noted that one of the psychology studies produced the best reported reduction in injury rates.[26] The authors of this study identified at risk athletes before administering the targeted intervention. Perhaps intervention studies need to be aimed at subgroups of athletes who may be at greater risk due to factors such as previous injury[9] or maturation level in this population.[6] There is limited evidence that supports the use of screening for injury prediction[44] but at a practical level it might be still useful to apply targeted interventions to pre-elite athletes with at-risk profiles.

There is a paucity of research with low risk of bias specific to injury prevention in the pre-elite population. We have identified a lack of exercise intervention studies for female pre-elite athletes. It is recommended that injury prevention interventions that have been shown to work in other athletic populations should be trialled in a variety of sports for pre-elite male and female athletes, and where possible trials should be conducted to ensure a low risk of bias and with intervention reporting standards such as CERT and WIDER.[20,21] None of the interventions included in this review utilised more than a single discipline approach; multimodal interventions may improve the observed effect given the complexity of injury aetiologies.[45] Greater attention needs to be directed toward implementation planning to bring about sustained intervention compliance in order to achieve injury reduction in the 'real-world'.[46] Finally, adoption of a model such as the FTEM framework allows greater consistency in the classification of the sporting population with clear descriptions of the requirements of each level.

This Systematic Review provides a synthesis and summary of evidence, as well as providing clear recommendations for future research investigating injury prevention interventions used in pre-elite athletes. A limitation of this review was the inability to perform a meta-analysis of results and the generally low number of published studies in this population. Additionally, although we employed a sensitive search strategy, we may have misclassified excluded articles due to low reporting standards of the level of athlete in many interventions.

5. Conclusion

There is limited evidence as to the efficacy or otherwise of exercise and psychological interventions for injury prevention in pre-elite athletes who compete in an Olympic or professional sport. No evidence is available for the use of equipment (mouthguards) and Vitamin D supplementation interventions for the pre-elite athletic population. None of the included studies demonstrated low risk of bias and intervention and implementation planning are not well reported in injury prevention research of pre-elite athletes limiting the ability to implement the results in the real-world. There needs to be a call to action across disciplines to address this apparent shortfall in the literature in order to inform effective practical outcomes.

What is already known?

- Injuries in pre-elite development are common.
- Injuries can compromise a developing athlete's sporting potential, reduce their chance of successful performance and can lead to athletes dropping out of the sport.
- Previous injury predisposes athletes to further injury.

What are the new findings?

- Exercise and psychological interventions may prevent injury in pre-elite athletes.
- There is insufficient evidence to evaluate the use of equipment and nutrition interventions in pre-elite athletes.
- There is a lack of level 1 evidence for injury prevention in the pre-elite population.
- More injury prevention intervention studies need to focus on female athletes.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.jsams.2019.03.002.

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46. Thorborg K, Krommes KK, Esteve E et al. Effect of specific exercise-based football injury prevention programmes on the overall injury rate in football: a systematic review and meta-analysis of the FIFA 11 and 11+ programmes. *Br J Sports Med* 2017; 51(7):562–571.

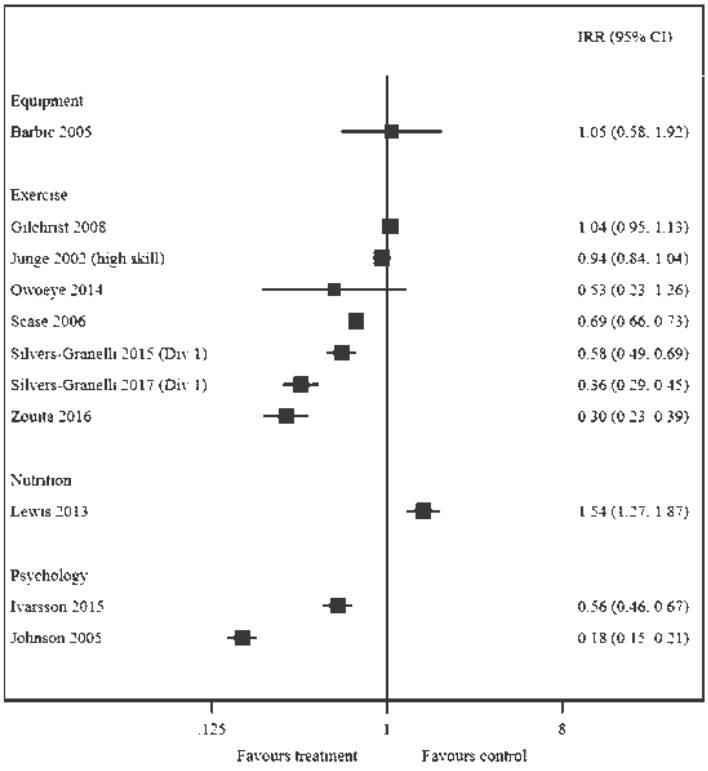


Figure 9 (Figure 4 in publication). Forest plot showing IRR and 95%CI of number of injuries in intervention group compared to control group. IRR: incidence rate ratio, CI: confidence interval.

Systematic review update

Methods

Subsequent to the published systematic review, an electronic search of the literature in MEDLINE, CINAHL, PubMed, SportDISCUS and Web of Science was repeated on 22 February 2021 with a date restriction of May 2017 onwards and English language only as a limitation. The same search strategy used in our published Systematic Review[104] was employed. All potential references were imported into Endnote X7 (Thompson Reuters, Carlsbad, California, USA) and then into Covidence (Covidence systematic review software, Veritas Health Innovation, Melbourne, Australia. Available at www.covidence.org) and duplicates removed. Titles and abstracts were independently screened for eligibility by two authors (ES and PN). The full text of each included study was then independently examined according to the inclusion and exclusion criteria used in our published Systematic Review, and reference lists of included studies were manually searched to find any further articles for inclusion. In the event of disagreement between authors, an additional author (GW) was consulted to reach

consensus. Data extraction from the published Systematic Review[104] was repeated and presented in the Tables below. Two authors (ES and MD) repeated an independent risk of bias assessment on each included article using the Cochrane Collaboration's tool for assessing the risk of bias in randomised trials (Figure 9).[105] As this new search was conducted for the purposes of updating our published Systematic Review,[104] the same risk of bias tool was applied despite two of the articles being cohort studies rather than randomised studies. Risk of bias for implementation was repeated by assessing each article against IM (Step 5) criteria (Figure 8).[77,79]

Results

The electronic search identified 1971 articles; duplicates were then removed, resulting in 1893 articles. The titles and abstracts were screened, which reduced the number of articles to 17. The full texts of these articles were obtained and assessed for eligibility against the inclusion criteria. No articles were added following citation checking. Fourteen studies were excluded due to not meeting the inclusion criteria. Two of the most common reasons for exclusion were 1) wrong patient population (n=8) and 2) insufficient detail (n=5). The three remaining articles were included for full review and data synthesis.[106-108] The flow chart of this process is presented in Figure 7.

Figure 10: PRISMA flow chart, PRISMA: Preferred Reporting Items for Systematic Reviews and Meta-Analyses

One article examined whether load management using the Acute:Chronic Workload Ratio (ACWR) could prevent health problems in male and female elite youth football (soccer) players.[106] The other two articles assessed the effectiveness of exercise programs to reduce injury.[107,108] More specifically, one of the exercise studies involved the delivery of a sensorimotor training intervention for male and female collegiate football (soccer) players. The other exercise study investigated the effect of a hip-focused injury prevention program for reducing the incidence of ACL injury in female collegiate basketball players.

The injury definitions and Injury Definitions Concept Framework (IDCF) classification for each study are outlined in Table 1. According to the IDCF classification, one study used athlete self-report[106] and the other two studies relied on clinical examination.[107,108] The level of strength according to guidelines previously published[109] and effectiveness based on IRR are outlined in Table 1. The strength of evidence was deemed to be limited for load management and moderate for exercise. The hierarchical level of

evidence was Level 2 for load management[106] and Level 3 for exercise because they were non-randomised cohort studies (Table 2).[107,108]

The risk of bias assessment is outlined in Figure 9. Risk of bias assessment concluded that these three studies were deemed at high risk of bias.[106-108] A major contributor to assessments of high risk of bias was lack of randomisation, blinding and allocation concealment.

The Consensus on Exercise Reporting Template (CERT) was employed to rate the reporting standard of the exercise studies. The following criteria has been previously applied[110]: studies satisfying >75% of criteria were considered to have a high level of reporting standard; 60–74% moderate; and those satisfying less than 60% of criteria were considered to have poor exercise reporting standards. The CERT scores were 53%[107] and 37%[108] for the exercise studies, which were therefore deemed to have poor reporting standards (Table 3).

There was no evidence of IM (Step 5) being employed to guide the implementation process for any of the included articles. Results are shown in Figure 8. Adopters and implementers were identified in all studies; however, there was no evidence of developing an implementation planning group or developing objectives, determinants, change objectives or strategies for reach, adoption and implementation. There was, however, some evidence of designing reach, adoption and implementation interventions.

Discussion

The two exercise studies were found to be effective for preventing injury in pre-elite athletes, which supports the findings of the published Systematic Review.[104] However, these studies were shown to have a high risk of bias and poor reporting standards. Load management as an intervention was not included in the published Systematic Review.[104] This subsequently identified study demonstrated that load management using the ACWR was not successful in preventing health problems in pre-elite footballers.[106] The authors identified that a major limitation of the study was the difficulty with assessing coaches' adherence to the intervention and the extent to which their training planning was influenced by the ACWR. Another limitation was a low (69%) average athlete response rate for the HPQ.

Table 2: Intervention – description of study participants, level of competition, incidence of injury of included studies, injury definition and injury definitions concept framework (IDCF)

Intervention type; Article	Participants (male/female)	FTEM level*, age (Age±SD)	Injury Incidence or Prevalence: Intervention (exposure)	Injury Incidence or Prevalence: Control/ pre-intervention (exposure)	IRR or RR (95%CI)	Injury definition	IDCF
Load management							
Dalen-Lorentsen, 2020. Does load management using the acute:chronic workload ratio prevent health problems? A cluster randomised trial of 482 elite youth footballers of both sexes.	Soccer (M&F)	FTEM: T 3/4 Con: 17.4 ± 1.1 Int: 17.2 ± 1.2	All health problems: 65.7% (61.1%–70.2%) Substantial health problem: 31.1% (26.7% – 35.5%)	All health problems: 63.8% (60.0% – 67.7%) Substantial health problem: 35.3% (31.6% – 39.1%)	All health problems: RR 1.01 (0.91–1.12); p=0.84 Substantial health problem: RR 0.88 (0.72–1.06); p=0.17	All complaints, irrespective of their consequences on football participation or their need to seek medical attention, including illness & injury.	
Exercise							
Reneker, 2019. Sensorimotor training for injury prevention in collegiate soccer players: An experimental study	Soccer (M&F) NCAA Div 2	FTEM: T 3 20.2 ± 1.46	8.94 injuries/1000 athlete exposures	11.8 injuries/1000 athlete exposures	IRR 0.76 (0.69–0.83); p=0.00	Occurred during participation in a NCAA-sanctioned practice or competition and required attention from an athletic trainer and or physician. Contusions and overuse injuries were not included.	
Omi, 2018. Effect of hip-focused injury prevention training for anterior cruciate ligament injury reduction in female basketball players. A 12-year prospective intervention study	College basketball (F) Equivalent to NCAA Div 2	FTEM: T3 19.6 ± 1.1	0.10 ACL injuries/1000 athlete exposures	0.25 ACL injuries/1000 athlete exposures	RR 0.38 (0.17–0.87); p=0.017	ACL injury diagnosed by a physician and verified by arthroscopy or magnetic resonance imaging.	

FTEM: Foundation, Talent, Elite, mastery Framework; IRR: Incidence Rate Ratio; IDCF: Injury definitions Concept Framework; NCAA: The National Collegiate Athletic Association; AE: Athlete Exposure; ACL: Anterior Cruciate Ligament

Table 3: Characteristics of the studies including data collection period, statistical analysis, efficacy, level of evidence.

Intervention; Article	Data collection period	Statistical analysis	Effectiveness/ level of strength for intervention type	Level of evidence (OCEBM Level)
Load management				
Dalen-Lorentsen, 2020. Does load management using the acute:chronic workload ratio prevent health problems? A cluster randomised trial of 482 elite youth footballers of both sexes.	Feb–Nov 2018	Outcome measures: Between-group difference in prevalence & relative risk ratio. Generalised estimating equations with intention-to-treat principle	X **Level of strength:** Limited	Level 2
Exercise				
Reneker, 2019. Sensorimotor training for injury prevention in collegiate soccer players: An experimental study	2017–2018	Descriptive statistics: means with standard deviation, counts with percentages. Right skewed outcomes: log-gamma mixed effect random intercept models. Normal outcomes: Gaussian random intercept models Injury rates: Poisson models	✓	Level 3
Omi, 2018. Effect of hip-focused injury prevention training for anterior cruciate ligament injury reduction in female basketball players. A 12-year prospective intervention study	2003–2014	Outcome measure: ACL injuries. Incidence rates Relative risk: chi-square analysis	✓ **Level of strength:** Moderate	Level 3

OCEBM: Oxford Centre for Evidence Based Medicine, ACL: Anterior Cruciate Ligament

Table 4:Intervention summary, duration and frequency, specific details of intervention (i.e., reps, sets, intensity, progression), co-intervention, reproducible, intervention reporting standard

Intervention; Article	Intervention summary	Duration & frequency	Specifics of intervention (reps, sets, intensity, progression)	Co-intervention	Reproducible	Intervention reporting standard (e.g., CERT)	
Load management							
Dalen-Lorentsen, 2020. Does load management using the acute:chronic workload ratio prevent health problems? A cluster randomised trial of 482 elite youth footballers of both sexes.	Individualised load management	NA	NA	Nil	No. A lot of variability in application.	NA	NA
Exercise						**CERT score (%)**	**Interpretation**
Reneker, 2019. Sensorimotor training for injury prevention in collegiate soccer players: An experimental study.	Vestibular, visual & oculomotor activities, cervical neuromotor control & strength training, and postural/balance exercises.	4 weeks 2 face-to-face sessions/week & home exercise program	Circuit of exercises face-to-face: (45mins total) 2–3 rounds, 5–6 exercises, 2.5–3.5 mins/station HEP: Horizontal gaze stability Near-point convergence Horizontal eye-head coordination	Nil	Yes.	10(53)	Poor
Omi, 2018. Effect of hip-focused injury prevention training for anterior cruciate ligament injury reduction in female basketball players. A 12-year prospective intervention study	Hip-focused injury prevention (HIP) training: Jump-landing +/- band Strengthening Balance	8 years. Education: 3/season HIP training: 20 mins, 3/week	Detailed program outlined in Table 2 of publication	Education for players, coaches & student athletic trainers	Yes.	7(37)	Poor

CERT: Consensus on Exercise Reporting Template; HEP: Home Exercise Program; HIP: Hip-focused Injury Prevention

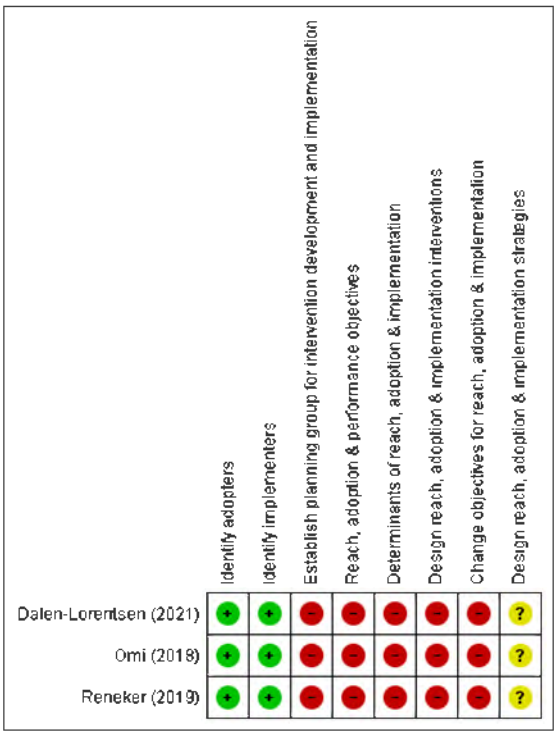


Figure 11:Intervention Mapping (IM) Step 5

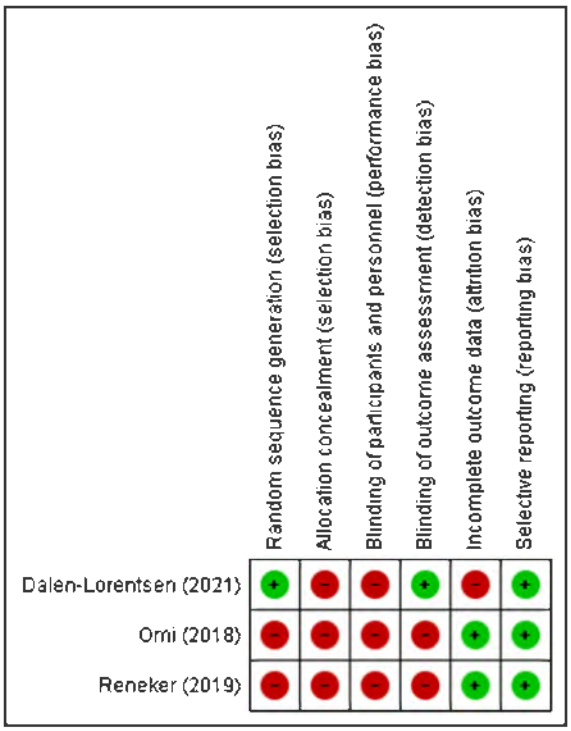


Figure 12:Risk of bias summary

Conclusion

Two of the additional studies that met the inclusion criteria support the finding of the published Systematic Review[104] that exercise interventions may prevent injury in pre-elite athletes. It is difficult to assess the effectiveness of load management in pre-elite athletes based on one study and, as such, more research in this area is indicated. On a final note, all the included studies from this new search included female athlete participants, which the studies from the published Systematic Review[104] were lacking.

Chapter 4 'Ideal conditions'/Scientific evaluation of the preventative measure (TRIPP 4)

Published work

This chapter is based on a manuscript that has been published in the journal, Physical Therapy in Sport.

> **Smyth E**, Waddington G, Witchalls J, et al. Does ankle tape improve proprioception acuity immediately after application and following a netball session? A randomised controlled trial. *Phys Ther Sport*. 2021; 48:20-25.

Chapter 3's systematic review identified level 2 and 3 evidence for exercise and psychology interventions preventing injury in pre-elite athletes. Additionally, there was an absence of evidence to support the use of equipment, nutrition and load management interventions within the pre-elite athlete cohort. This third study provides evidence for the use of tape (i.e., equipment) in pre-elite netball athletes.

The most frequent injury reported at the 2018 ANNC was ankle sprain. A recent literature review[111] supported the use of a brace or tape to reduce the risk of recurrent and initial ankle sprain. Additionally, a significant association between poor single leg balance and ankle sprain has been identified.[112] To control balance, the central nervous system (CNS) combines visual, vestibular, and proprioceptive information to coordinate the activation patterns of muscles.[113] At the time of this thesis being developed, Netball Australia had a universal prevention policy requiring all pre-elite athletes to tape their ankle for training and matches. Therefore, to assess the efficacy or effectiveness of injury prevention in this population was deemed unfeasible as it would require removing preventative actions from the group. Discussion with Netball Australia and relevant ethics committees determined that removing a preventative action was not ethical, noting it would be the best scientific approach. Therefore, we decided to test the hypothesis that ankle tape improves proprioception to determine if there is evidence to support the rationale for the continued use of the ankle taping policy. It also provides evidence for whether there is a difference between a Sport and Exercise Physiotherapist (SEP) taping

an athlete's ankle and an athlete performing self-applied taping, which has practical and clinical importance.

Co-authors' declaration

Declaration of Co-Authored Publications

UNIVERSITY OF CANBERRA

For use in theses which include co-authored publications. This declaration must be completed for each co-authored publication and to be placed at the start of the thesis chapter in which the publication appears, or as a preface to the thesis.

Declaration for Thesis Chapter Four

Publication: "Does ankle tape improve proprioception acuity immediately after application and following a netball session?: a randomised controlled trial"

DECLARATION BY CANDIDATE

In the case of Chapter Four, the nature and extent of my contribution to the work was the following:

Nature of Contribution	Extent of Contributions (%)
Conception and design of the research proposal	80%
Data collection	50%
Analysis and interpretation of the findings	70%
Writing the paper and critical appraisal of content	70%
Corresponding author for journal communication and publication peer-review process.	100%

The following co-authors contributed to the work:

Name	Nature of Contribution	Contributor is also a UC student (Yes/No)
Gordon Waddington	Conception and design of the research proposal Data collection Analysis and interpretation of the findings Writing the paper and critical appraisal of content	No
Jeremy Witchalls	Data collection Analysis and interpretation of the findings	No
Phillip Newman	Analysis and interpretation of the findings Writing the paper and critical appraisal of content	No
Juanita Weissensteiner	Writing the paper and critical appraisal of content	No
Steven Hughes	Data collection	No
Theo Niyosenga	Analysis and interpretation of the findings	No
Michael Drew	Conception and design of the research proposal Analysis and interpretation of the findings Writing the paper and critical appraisal of content	No

Candidate's Signature

17/09/2021

Date

Declaration of Co-Authored Publications

UNIVERSITY OF CANBERRA

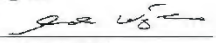
DECLARATION BY CO-AUTHORS

The undersigned hereby certify that:

(1) the above declaration correctly reflects the nature and extent of the candidate's contribution to this work, and the nature of the contribution of each of the co-authors.
(2) they meet the criteria for authorship in that they have participated in the conception, execution, or interpretation, of at least that part of the publication in their field of expertise;
(3) they take public responsibility for their part of the publication, except for the responsible author who accepts overall responsibility for the publication;
(4) there are no other authors of the publication according to these criteria;
(5) potential conflicts of interest have been disclosed to (a) granting bodies, (b) the editor or publisher of journals or other publications, and (c) the head of the responsible academic unit; and
(6) the original data are stored at the following location(s) and will be held for at least five years from the date indicated below:

[Please note that the location(s) must be institutional in nature, and should be indicated here as a department, centre or institute, with specific campus identification where relevant.]

Location(s):	Australian Institute of Sport

Gordon Waddington
Signed: 
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Jeremy Witchalls
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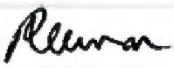
Date: 03/09/2021

Phil Newman
Signed: 
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Date: 3/9/2021

Theo Niyosenga
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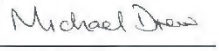
Signed: 
Date: 17/09/2021

Does ankle tape improve proprioception acuity immediately after application and following a netball session? A randomised controlled trial

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Original Research

Does ankle tape improve proprioception acuity immediately after application and following a netball session? A randomised controlled trial

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ABSTRACT

Objectives: To assess whether ankle tape applied by a Sport and Exercise Physiotherapist (SEP) or self-applied by the athlete results in a change in proprioception and whether it is maintained during a netball session.
Design: Randomised controlled trial.
Setting: Australian Institute of Sport.
Participants: 53 pre-elite netball athletes.
Main outcome measures: Athlete proprioception was assessed using the Active Movement Extent Discrimination Apparatus (AMEDA) on four occasions for each taping condition: 1) pre-tape, 2) post-tape, 3) post-netball & 4) post-netball no-tape.
Results: Mixed effect linear models were used for analysis. A significant increase in proprioception was observed when self-tape: 0.022 (95% CI: [-0.000 – 0.044], p = 0.05), and SEP tape: 0.034 (95% CI: [0.012 –0.055], p < 0.01), were initially applied. These improvements were maintained during a netball session for both, self-taping: 0.01 (95% CI: [-0.01 – 0.02], p = 0.45) and SEP-taping: <0.01 (95% CI: [-0.02 – 0.01], p = 0.56). Results also indicate there was no significant difference between taping conditions (β = –0.001, 95% CI: [-0.02 – 0.02], p = 0.90).
Conclusions: Proproioception improves and is maintained during a netball session with either SEP or self-applied taping.

Introduction

Ankle sprains have been reported to have the highest injury incidence in the sport of netball (Finch et al., 2002; Hume & Steele, 2000; Langeveld et al., 2012), particularly in 17/U & 19/U netball athletes (Hume & Steele, 2000). Taping is often recommended as a strategy for preventing ankle sprain (Verhagen & Bay, 2010), but the mechanism by which taping works is not completely understood. Taping and bracing have been shown to reduce the risk of initial and recurrent ankle sprains (Vuurberg et al., 2018). Studies have shown that the mechanical protection offered by tape declined nearly completely after 45 minutes (Best et al., 2014) with a reduction after 10 minutes of sporting activity (Verhagen et al., 2001) thereby challenging mechanical protection as the sole mechanism for effectiveness.

Improved proprioception, defined as the perception of body position and movements in three-dimensional space (Han et al., 2016), has been widely accepted as a plausible reason for injury prevention. It is hypothesised that tape stimulates the cutaneous sensory receptors of the leg and foot, resulting in better awareness of foot position and muscle activation prior to, and during, foot contact with the floor (Robbins et al., 1995; Semple et al., 2012). A

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1466-853X/

recent systematic review refutes these claims, concluding that using an ankle brace or ankle tape has no effect on proprioception acuity in participants with recurrent ankle sprain or functional ankle instability (Raymond et al., 2012). The majority of ankle tape studies investigating proprioception have not been performed in the last decade (Halseth et al., 2004; Refshauge et al., 2009; Simoneau et al., 1997), and we now have more sophisticated methods for assessing proprioception (Han et al., 2016).

The ankle Active Movement Extent Discrimination Apparatus (AMEDA) is a device used to measure proprioception of the ankle joint in a functional context. It is a purpose-built device constructed by the project team for research purposes. Using a dynamic platform, the device records the athlete's accuracy in discriminating changes in floor angle while moving a foot plate actively, standing up, with body weight on the feet (Steinberg, Waddington, Adams, & et al, 2016). This testing apparatus has evolved over the last 20 years, resulting in a user friendly, reliable (Witchalls et al., 2014) and valid (Han et al., 2016; Lewkowicz, 2001) measure of proprioception. Availability of this sophisticated apparatus warrants reassessment of the effect tape has on proprioception.

This study will contribute to the evidence by examining whether ankle taping changes proprioceptive acuity and whether it is maintained during a netball session. We will also assess whether athlete self-taping is less effective than if the tape was applied by trained personnel. This research gives us the opportunity to test whether the different taping techniques result in different proprioceptive acuity.

This paper will aim to answer the following questions:

1) Does tape improve the ankle proprioception of pre-elite netball athletes?
2) If pre-elite netball athlete proprioception improves with the application of tape, is it maintained during a netball session?
3) Is there a difference in proprioception change when pre-elite athletes apply their own tape compared with a Sport & Exercise Physiotherapist (SEP) applying the ankle tape?

Methods

Participants

We recruited a representative sample of pre-elite netball players to further investigate taping in this population. A situation camp hosted by the national netball organisation represented the most feasible and most comparable training programs, environment, equipment, staff and stage of the season. All fifty-three pre-elite netball athletes (athletes with a State Academy/Institute scholarship) attending the camp were invited to take part in this randomised controlled trial. They were attending a netball camp at the Australian Institute of Sport from the 11–14 December 2018. Sample size was based on previous published data demonstrating statistical significance using similar testing protocols (Long et al., 2017; Steinberg et al., 2015).

Athletes were excluded if they had a current injury preventing them from full netball participation. All athletes were female and the mean age was 17.7 (range 16–23). Given that the athletes regularly tape their ankles, a superiority randomised controlled trial was employed as it was deemed unacceptable to withhold taping from athletes by the sporting organisation.

Protocol

Proprioceptive acuity was tested using the AMEDA (Waddington & Adams, 1999). The athlete stood with one foot on a fixed platform and the other on a moveable plate with the pivot axis through the centre of the footprint, allowing inversion movement of the ankle. The computer-controlled stepper motor device provides five exact inversion angles at one-degree intervals between 10 and 14 degrees of inversion, and the test determines the sensitivity of the individual with respect to detecting differences between the positions. Each athlete was familiarised with the AMEDA apparatus before data collection commenced. This included an explanation and then three trials of the five-movement displacement distances, in order, from the smallest to the largest: fifteen movements in total. Athletes then performed 50 trials of testing, in which all five positions were presented ten times, in a random order. Each trial consisted of one active inversion movement out to a stop at a steady pace, followed by return to the start position. After each trial, the athlete was asked to make a judgement as to the position number (1–5) of each test movement. They were not provided with any feedback regarding the correctness for each trial. They relied on their memory of the five movement extents from the familiarisation session to enable them to identify each trial and make a numerical judgement (1–5) (Han et al., 2016). AMEDA results were generated using the receiver operating characteristic (ROC) method (Maher & Adams, 1996). The area under the curve (AUC) measures were averaged over the five movement stimulus set to give a single discrimination score for each test.

Following the first proprioception assessment, athletes were randomly allocated to either a self-applied or SEP applied taped group using computer generated randomisation. The lead author (ES) generated the random allocation sequence, enrolled athletes and assigned athletes to the taping conditions. Following ankle taping, the athlete's proprioception was promptly assessed again using the same protocol. AMEDA testers were blinded to the taping condition. Immediately after a netball session, proprioception was assessed with tape insitu and again after the tape was removed. This was to assess whether tape was influencing proprioception following a netball session. These final two assessments occurred within 20 minutes of completing the netball session. There was a minimum of 6 hours between the 1st and 2nd netball sessions. To assess whether there was equal loads across athletes, individual loads were monitored using the ClearSky T6 local positioning system[a] (Catapult Sports, Melbourne, VIC, Australia). The ClearSky system utilizes ultra-wideband anchor nodes to triangulate the location of receiver tags, secured inside a vest and worn between the scapulae of each athlete (Luteberget et al., 2018; Serpiello et al., 2018). This provides indoor motion analysis (i.e. total distance, average velocity etc.) for athletes. Testing was performed court side at the Australian Institute of Sport indoor netball courts and a crossover design was employed so that each athlete experienced both tape conditions.

The SEP applied tape consisted of applying 'skin-prep', then 5 cm microfoam[b] (3 M Australia) to the anterior and posterior ankle to prevent tape cut. The athlete sat on a physiotherapy plinth in a long sit position with the ankle dorsiflexed. Rigid 38 mm sports tape[c] (Elastoplast Leuko Premium) was used to apply an anchor at the distal 1/3 shin, 2 x medial to lateral stirrups, 2 × 6's starting and ending laterally, 1 x half heel lock starting and ending laterally, 1 x half heel lock starting and ending medially, 2–3 closing anchors, ensuring full skin coverage of the bottom 1/3 leg (Fig. 1). (Zuluaga, 1995) The self-tape group were encouraged to apply tape in the manner that they normally do, using the same products used by the Sports & Exercise Physiotherapist.

Ethics approval was obtained from the University of Canberra Human Research Ethics Committee and written informed consent was gained from athletes or their parents/legal guardians before commencement of data collection. The CONSORT standards of reporting of RCTs were followed (Schulz et al., 2010).

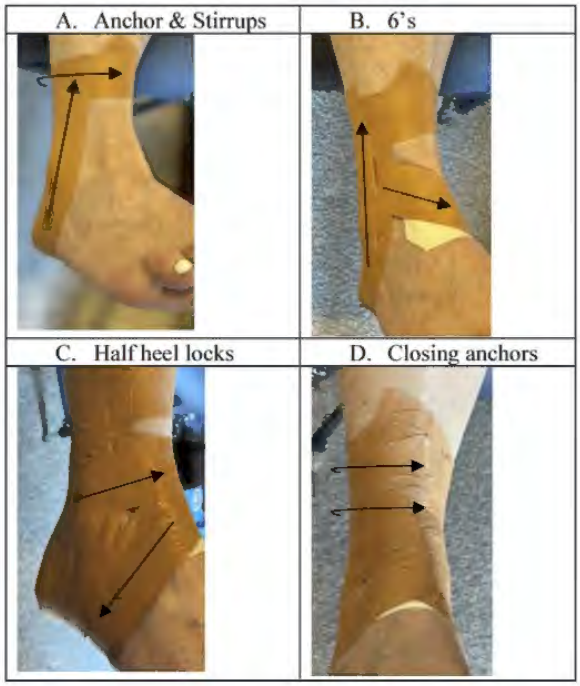

Fig. 1. Sport & Exercise Physiotherapist taping method.

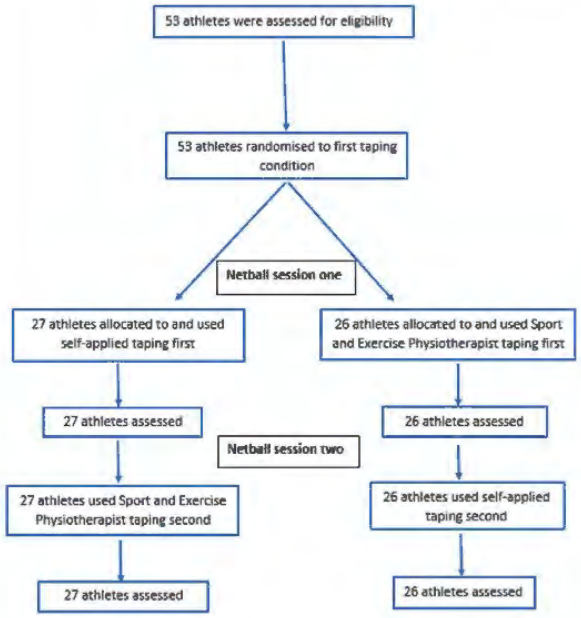

Fig. 2. CONSORT flowchart.

Statistical analysis

Data were analysed using STATA® statistical software[d] (STATA®/IC 15; StataCorp, College Station, TX, USA). A mixed effects linear model was used to test the effect of the SEP intervention (SEP versus self-applied applied taping) on athletes' ankle AMEDA scores as well changes in AMEDA score over time. The fixed effects were the testing period (pre-tape, post-tape, post-netball, or post-netball no-tape), the tape condition (self-applied or SEP applied) and the order of condition (self-applied or SEP applied tape first). A random effect for participant was included in models to account for within player covariance as players were repeatedly measured over time and conditions. A three-way interaction model (order, tape, testing period) was employed to assess learning effect. A two-way interaction model (tape, testing period) was used to analyse tape effect as there was no significant interaction between tape and testing period. We used the Wald test to determine model significance. The likelihood ratio test was utilised to compare models with and without random effects. It was hypothesised that workload in the training session may affect the AMEDA results, therefore total minutes and distance (metres) covered in each session were compared for each tape condition (self-applied or SEP applied) using mixed effect linear models with random effect for participant. These models included a two-way interaction between minutes and distance with the player as a random effect to account for within player covariance. The a priori level of significance was set at $\alpha = 0.05$ with 95% confidence intervals (95% CI) reported to indicate the precision of estimates.

Results

All 53 netball athletes completed testing with the two different tape conditions (Fig. 2). All netball sessions were 45–60 minutes in duration and consisted of either netball specific drills with a ball or match-play. All mean AMEDA scores are presented in Table 1 and Fig. 3. The participant random effect was significant (χ (Hume & Steele, 2000) = 122.1, $p < 0.01$) and the overall significance of the mixed-effects restricted maximum likelihood (REML) regression was significant (Wald $\chi^2_7 = 21.72$, $p < 0.01$). The athletes who had SEP taping for the first session and self-taping for the second session improved their pre-test by 0.053 (95% CI: [0.032–0.073], $p < 0.01$) and the athletes that had self-applied tape for the first session and SEP applied taping for the second session improved their pre-test by 0.058 (95% CI: [0.036–0.080], $p < 0.01$).

A significant increase in AMEDA score, indicating improved proprioception was observed when SEP applied tape, 0.034 (95% CI: [0.012–0.055], $p < 0.01$) and self-applied tape, 0.022 (95% CI: [-0.000 – 0.044], $p = 0.05$), were initially applied. These improvements were maintained during a netball session for both, self-applied tape: 0.01 (95% CI: [-0.01 – 0.02], $p = 0.45$) and SEP applied taping: 0.00 (95% CI: [-0.02 – 0.01], $p = 0.56$). Results also indicate that there was no significant difference in AMEDA scores between self-applied or SEP applied taping conditions ($\beta = -0.001$, 95% CI: [-0.02 – 0.02], $p = 0.90$). There was no statistically significant difference (Wald $\chi^2_7 = 0.80$, $p = 0.85$) in minutes ($\beta = -0.001$, 95% CI: [-0.07 – 0.06], $p = 0.84$) and distance ($\beta = -0.0005$, 95%CI: [-0.002 – 0.001], $p = 0.52$) for either tape condition.

Discussion

A significant improvement in proprioception was observed when either SEP or self-tape were applied. This improvement was maintained for both tape conditions during a netball session. Additionally, there was a learning effect between the 1st and 2nd session of testing (i.e. between the 1st and 5th AMEDA assessment) for both tape conditions. The implications of this study are that either taping condition is acceptable and will equally improve the ability of a pre-elite netball athlete to discriminate small

Table 1
AMEDA scores for session one and two.

	Pre-tape (mean ± SD)	Post-tape (mean ± SD)	Post-netball (mean ± SD)	Post-netball, no tape (mean ± SD)
Session 1				
Combined	0.64 ± 0.06	0.67 ± 0.06	0.68 ± 0.06	0.69 ± 0.05
Self-applied tape	0.64 ± 0.06	0.66 ± 0.06	0.68 ± 0.07	0.69 ± 0.06
SEP applied tape	0.65 ± 0.06	0.69 ± 0.05	0.68 ± 0.05	0.69 ± 0.04
Session 2				
Combined	0.70 ± 0.05	0.70 ± 0.05	0.69 ± 0.06	0.70 ± 0.05
Self-applied tape	0.70 ± 0.05	0.71 ± 0.05	0.71 ± 0.06	0.71 ± 0.04
SEP applied tape	0.69 ± 0.05	0.69 ± 0.05	0.68 ± 0.06	0.70 ± 0.06

AMEDA (Active Movement Extent Discrimination Apparatus) scores are presented for both testing sessions. Scores for both groups 1) Self-applied tape and 2) Sport and Exercise Physiotherapist (SEP) tape are presented.

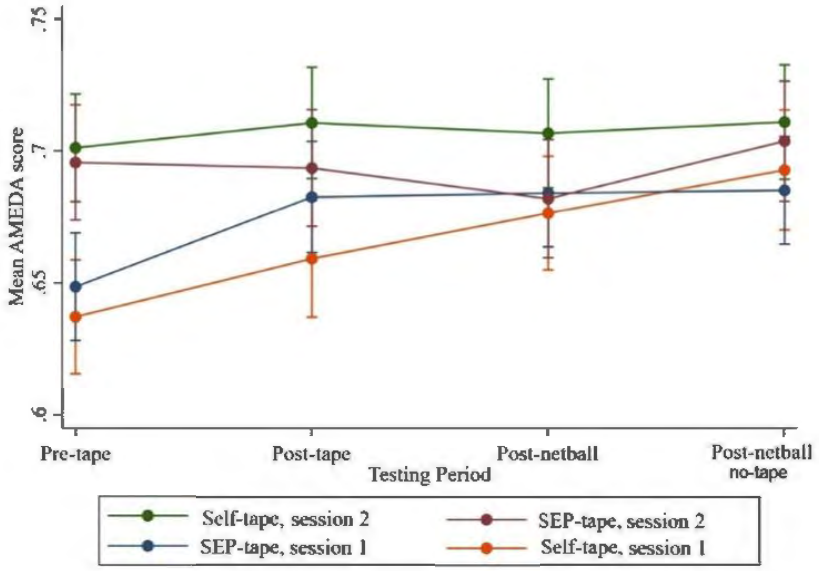

Fig. 3. Mean AMEDA (Active Movement Extent Discrimination Apparatus) scores are presented for each taping condition (Self-tape/SEP*-tape) and session number (session 1/session 2) across the four testing periods (Pre-tape/Post-tape/Post-netball/Post-netball no-tape).
*SEP: Sport and Exercise Physiotherapist.

movements at the ankle. It may inform scientists as to the mechanisms for the observed protective effect of taping on ankle sprains.

A significant improvement in proprioception was observed when either SEP *or* self-tape were applied. This contradicts the systematic review (Raymond et al., 2012) reporting no improvement in proprioception but the *four* papers reporting no *improvement* used alternative assessment tools i.e. non-weight bearing threshold to detection of passive motion (Hubbard & Kaminski, 2002; Refshauge et al., 2000, 2009) or joint position reproduction with contralateral side (Schenker, 1989). However, it has been previously noted that different methods of proprioception testing do not correlate strongly to each other when testing the ankle (de Jong et al., 2005), so the selection of the most relevant tool is important to each context. A review comparing three methods for testing proprioception: threshold to detection of passive motion, joint position reproduction and active movement extent discrimination (Han et al., 2016) suggests that the AMEDA is the most effective method for assessing proprioception during active, functional body movements that occur in most sports. Therefore, the findings from this study are more applicable when compared to previous studies investigating the effect of tape on proprioception.

The current study demonstrates that proprioception is maintained during a netball session, and this improvement is apparently independent of either SEP applied or self-applied tape conditions ($p = 0.90$). A study undertaken in New Zealand (Waterman et al., 2004) using athletes participating in the two highest grades of club netball showed that proprioception deteriorated during a netball match. It is not clear whether any of the participants in that study wore ankle tape during the proprioception testing or netball match. Our findings are supported by research that showed following a 30 min exercise session consisting of running and basketball, joint position sense was 2.5% worse when their male university student participants were taped compared to 35.5% worse when they did not wear tape (Robbins et al., 1995). There is evidence that reduced proprioception increases the rate of ankle sprain (Attenborough et al., 2017; Witchalls et al., 2012) and the findings of the current study support continuing the common practice of ankle taping for netball sessions to help minimise any potential reduction in proprioception during play or training.

An AMEDA learning effect was found when comparing proprioception scores at the start of the second session compared to the

start of the first session of testing. This is comparable to previous studies using the AMEDA to assess proprioception (Steinberg et al., 2016; Witchalls et al., 2014). This suggests that either the employed familiarisation protocol was inadequate or four exposures to the assessment on the AMEDA results in a positive training effect. However, if the observed improvement in proprioception was solely due to learning effect rather than tape effect, we would expect to see consistent improvement in proprioception at each trial. The AMEDA continues to be a valid and reliable tool for proprioception but it may also be used for its training effect.

Study limitations

A first limitation of this study is the apparent learning effect of the AMEDA. If this could be eliminated it would provide greater certainty in determining the contributing effects of the tape and the netball session. In our study, we pre-planned to minimise this in the design stage by randomising order and using each participant as their own control. Nonetheless, this effect was still observed and future studies may require an additional training session to ensure the initial learning effect on the AMEDA is reduced. A second limitation of our study is our inability to have a passive control where no taping occurred. The netball organisations we worked with had a universal prevention program in place, which encourages athletes to tape at each training or competition event. Therefore, we rather opted to assess whether self-taping or SEP taping is superior, using a superiority randomised controlled trial (RCT) methodology. We are unable to report results comparing self-taping or SEP taping to a no-taping condition.

Conclusions

This study has demonstrated that tape does improve proprioception and it is maintained during a netball session. There was no difference in response whether the tape was self-applied or applied by trained personnel. It was beyond the scope of this paper to determine whether poor proprioceptive performers had a better response to tape or whether athletes with an injury history had reduced proprioceptive scores compared to uninjured athletes as previously described (Long et al., 2017; Steinberg et al., 2019). This information could change the common practice of all netball athletes taping prophylactically to only netball athletes with a history of ankle injury or reduced proprioceptive performance only taping routinely and should be investigated in the future. Nevertheless, our current findings continue to support the use of routine ankle taping for netball pre-elite athletes.

Ethical statement

Ethics approval was obtained from the University of Canberra Human Research Ethics Committee(Ref: 20,181,527) and written informed consent was gained from athletes or their parents/legal guardians before commencement of data collection.

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Suppliers

[a] ClearSky T6 local positioning system: Catapult Sports, Melbourne, VIC, Australia.

[b] 5 cm microfoam: 3 M Australia, NSW, Australia.

[c] Rigid 38 mm Leuko Premium sports tape: Elastoplast, Beiersdorf Australia Ltd, NSW, Australia.

[d] STATA® statistical software: STATA®/IC 15; StataCorp, College Station, TX, USA.

Declaration of competing interest

None declared.

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Chapter 5 Describing intervention context to inform implementation strategies (TRIPP 5)

Published work

This chapter is based on a paper that has been published in the journal, International Journal of Sport Science & Coaching.

> **Smyth E**, Appaneal R, Drew M, et al. Identifying the challenges to implementing a neuromuscular warm-up in pre-elite netball. *Int J Sports Sci Coach*. 2021;16(4):913-924.

Ankle sprains were the most frequently reported injury and ACL ruptures were the most severe at the 2018 17/U & 19/U ANNCs.[114] Over the past two decades ankle sprains and knee injuries have had the highest incidence of reported injuries in the sport of netball.[57,58,115] Kreisfeld et al.,[116] reporting on sports injury hospitalisation within Australia in 2011–12, identified that in netball, knee and lower leg injuries were the most frequently injured body region (60% of all netball injuries) with the youngest age group (15–17yrs) having the highest incidence rate.

Netball Australia, Australia's governing netball body, introduced the 'Knee injury prevention for Netballers and Enhance performance and Extend play' (KNEE) program in 2015. The aim of this program is to reduce not only knee injuries but all lower body injuries and to enhance performance by improving movement efficiency, strength and power.

Netball Australia developed a website (https://knee.netball.com.au) with resources to assist with implementing the KNEE program in junior, recreational and elite level netball programs. There is evidence demonstrating that high athlete compliance with an injury prevention program leads to significantly lower injury risk compared to an intermediate or lower level of compliance.[117] Each head coach at the 2019 17/U & 19U ANNC was contacted by email in April 2019 and followed up in person if an email response was not received, to determine athlete compliance to the KNEE program. It was revealed that 38% of teams competing at the 2019 17/U & 19U ANNC were not completing the KNEE program as frequently as recommended (i.e., 2–3 times/week). A recent observational study of

community junior netballers also demonstrated a lack of compliance to the KNEE program,[94] suggesting a review of the KNEE program's implementation is required.

Concept Mapping (CM) was used to harness and organise the ideas of netball coaches, strength & conditioning coaches and physiotherapists about the challenges they faced when implementing the KNEE program. The primary aim of this approach was to recognise gaps within the system implementation of this program and, in turn, develop viable and practical solutions including engagement and education to support compliance and in turn, the impact of the program. The process adopted within this study, partly fulfills the requirements of TRIPP Stage 5.

Co-authors' declaration

Declaration of Co-Authored Publications

UNIVERSITY OF CANBERRA

For use in theses which include co-authored publications. This declaration must be completed for each co-authored publication and to be placed at the start of the thesis chapter in which the publication appears, or as a preface to the thesis.

Declaration for Thesis Chapter Five

Publication: "Identifying the challenges to implementing a neuromuscular warm-up in pre-elite netball using concept mapping"

DECLARATION BY CANDIDATE

In the case of Chapter Four, the nature and extent of my contribution to the work was the following:

Nature of Contribution	Extent of Contributions (%)
Conception and design of the research proposal	60%
Data collection	80%
Analysis and interpretation of the findings	60%
Writing the paper and critical appraisal of content	70%
Corresponding author for journal communication and publication peer-review process.	100%

The following co-authors contributed to the work:

Name	Nature of Contribution	Contributor is also a UC student (Yes/No)
Gordon Waddington	Writing the paper and critical appraisal of content	No
Alanna Antcliff	Conception and design of the research proposal Analysis and interpretation of the findings	No
Phil Newman	Writing the paper and critical appraisal of content	No
Juanita Weissensteiner	Writing the paper and critical appraisal of content	No
Renee Appaneal	Conception and design of the research proposal Analysis and interpretation of the findings Writing the paper and critical appraisal of content	No
Alex Donaldson	Conception and design of the research proposal Analysis and interpretation of the findings Writing the paper and critical appraisal of content	No
Michael Drew	Conception and design of the research proposal Analysis and interpretation of the findings Writing the paper and critical appraisal of content	No

Candidate's Signature

17/09/2021

Date

DECLARATION BY CO-AUTHORS

The undersigned hereby certify that:

Declaration of Co-Authored Publications

(1) the above declaration correctly reflects the nature and extent of the candidate's contribution to this work, and the nature of the contribution of each of the co-authors.
(2) they meet the criteria for authorship in that they have participated in the conception, execution, or interpretation, of at least that part of the publication in their field of expertise;
(3) they take public responsibility for their part of the publication, except for the responsible author who accepts overall responsibility for the publication;
(4) there are no other authors of the publication according to these criteria;
(5) potential conflicts of interest have been disclosed to (a) granting bodies, (b) the editor or publisher of journals or other publications, and (c) the head of the responsible academic unit; and
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Identifying the challenges to implementing a neuromuscular warm-up in pre-elite netball using concept mapping

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Identifying the challenges to implementing a neuromuscular warm-up in pre-elite netball

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Abstract

Objective: To identify challenges for implementing Netball Australia's 'Knee injury prevention for Netballers and Enhance performance and Extend play' (KNEE) program for 17/U & 19/U State (i.e. regional/provincial representative) teams.

Design: Concept mapping, a mixed-methods approach incorporating qualitative and quantitative data collection and analyses.

Setting: Pre-elite netball.

Participants: Thirty-nine netball coaches, strength & conditioning coaches and physiotherapists working with State 17/U & 19/U teams.

Methods: Participants brainstormed challenges to implementing the KNEE program, sorted the challenges into groups based on similar meaning and rated the importance and difficulty of overcoming each challenge on a scale from 0 (least important/easiest to overcome) to 5 (most important/hardest to overcome).

Results: Forty-six statements (i.e. challenges) were identified and organised into the following eight clusters (mean importance rating out of 5, mean difficulty rating out of 5): 'athlete engagement' (3.31, 2.48); 'supervision and correction of technique' (3.03, 2.67); 'time constraints' (2.79, 2.59); 'athlete technique' (2.70, 2.64); 'education' (2.56, 2.16); 'support staff resourcing' (2.51, 2.67); 'program flexibility and adaptability' (2.02, 1.85); and 'coach and support staff prioritisation' (1.95, 1.81). Nineteen statements/challenges had above average ratings for importance (2.63) and difficulty (2.41).

Conclusions: This study identified 'athlete engagement', 'supervision and correction of technique', 'time constraints', 'athlete technique', 'education' and 'support staff resourcing' as the most important and difficult challenges to implementing the KNEE program in pre-elite netball. These multi-factorial challenges are the main barriers to implementing the KNEE program. They can be addressed using the implementation driver's framework.

Keywords

Athlete development, knee injury prevention, physiotherapy, sports technique, strength and conditioning

Introduction

Athlete development is often negatively impacted by injury.[1] Ankle sprains and knee injuries have the highest injury incidence in the predominantly female sport

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of netball,[2–5] particularly in 17/U & 19/U pre-elite female netball athletes.[3] Pre-elite athletes have been formally recognised as having future high performance potential, often rewarded with financial support but not yet selected for senior international competition or a senior professional team.[6] A study of Australian sports injury hospitalisations in 2016–17 identified that hip and lower limb injuries were the most frequently injured body region in netball (57% of all netball injuries), and 15–24 year old athletes had the highest incidence rate.[7] In pre-elite netball, approximately 2% of participants will have an ACL injury in the National tournament.[5] It has been shown in other sports[8,9] that injuries sustained by pre-elite athletes can lead to premature sports career termination. These studies highlight the need to successfully implement effective lower limb injury preventative strategies.

Netball Australia, Australia's governing netball body, introduced the 'Knee injury prevention for Netballers and Enhance performance and Extend play' (KNEE) program in 2015.[10] The KNEE program aims to reduce knee injuries and all lower body injuries and to enhance athletic performance by improving movement efficiency, strength and power. The KNEE program applies principles from evidence-based injury prevention programs in other sports including football,[11–13] basketball[14] and handball.[15] KNEE consists of footwork, strength, balance, landing and agility activities. The KNEE program takes approximately 15–20 mins to complete and should be performed before each court work or match play session at least twice a week. Netball Australia developed a website (https://knee.netball.com.au) with resources to assist with implementing the KNEE program in junior, recreational and elite netball programs. Pre-elite netball athletes are encouraged to use the 'elite' KNEE program.

The effectiveness of preventive strategies, like the KNEE program, is determined in part by athlete compliance rates. High compliance leads to significantly lower injury risk compared to intermediate compliance.[16,17] Athlete and coach compliance with completing and delivering lower limb injury prevention programs across several sports and settings is low.[18–23] Therefore, understanding the program implementation barriers will assist researchers and policy makers to improve the frequency of use of the KNEE program in this pre-elite netball population. Barriers to implementing injury prevention programs have been investigated in football,[19,20,23–26] basketball[19] and netball.[27] The netball study explored the challenges to implementing a program teaching safe-landing techniques to community junior netballers and identified a need to modify the program to make it more suitable for younger players and that more coach education was required.[27] To the best of our knowledge, this is the only previous research investigating the implementation of an injury prevention intervention in non-elite netball. Given the high number of ankle and knee injuries in pre-elite netball there is a critical need for the current study to inform the implementation of a program to reduce these lower limb injuries.[2–5] The aim of this study was to explore the challenges to implementing the KNEE program encountered by netball coaches, strength & conditioning (S&C) coaches and physiotherapists of pre-elite netball teams in Australia.

Methods

Study design: Concept mapping

As we were interested in exploring the applied, context-specific knowledge of the coaches and support staff of State (i.e. regional/provincial representative) 17/U & 19/U female netball teams in Australia, this study used concept mapping (CM).[28,29] Females were the focus of this study as netball is a female dominated sport and currently there are no pre-elite male representative teams in Australia. CM is a mixed-methods approach incorporating qualitative and quantitative data collection through participants' brainstorming of ideas, sorting of ideas, and rating of ideas. This research method has been previously used for injury prevention research in public health[30] and in sport.[26,31,32] Participants completed brainstorming, sorting and rating using the Concept Systems Global MAX[33] online platform. The authors also used this platform to analyse the data and to generate concept maps and additional displays of the data.

Brainstorming

Participants were asked to write a brief statement (one idea) to complete the following focus prompt: "*A challenge for me to implement the KNEE program with the state 17/U and 19/U teams I work with is . . . . .*". Once contributed, every idea is included in a pooled list of statements generated by those that have participated already and can be viewed by all participants. Participants were encouraged to add multiple statements and review statements made by others to check if an idea had already been contributed.

Statement synthesis

Three authors (ES, AD, RA) synthesised and edited the brainstormed challenges to ensure they were relevant to the project focus, contained a set of unique ideas with each idea represented once, and that each statement was clear. This iterative process involved: 1) identifying and deleting statements not related to the focus

prompt; 2) identifying and splitting statements with two or more unique ideas; 3) identifying and editing statements as required to ensure all members of the group agreed on the essential meaning of the statement; and 4) identifying statements that represented the same idea, selecting the statement that best represented the idea and deleting the other similar statements. Synthesising and editing occurred in one meeting until consensus was reached among the three authors. The resulting list of synthesized statements were made available to participants to complete the sorting and rating process.

Statement sorting

Using the Concept Systems Global MAX website, participants sorted the synthesised statements into themed groups. They were instructed to sort the statements into groups according to similarity in meaning and to name each group based on its theme. They were informed that the number of groups people create varies, and 5 to 15 groups was recommended as a guideline to organise the statements.[33,34] If any statements were not sorted, ES followed up with the participant to ensure this was intentional.

Statement rating

Participants were asked to rate each of the synthesised statements by answering the following questions: '*On a scale from 0 (least important) to 5 (most important), how important do you think this challenge is to using the KNEE program with the State 17/U and/or 19/U team (s) you work with?*'; and '*On a scale from 0 (easiest to overcome) to 5 (hardest to overcome) how difficult is this challenge for you to overcome when using the KNEE program with the State 17/U and/or 19/U team(s) you work with?*'.

Procedures

Netball Australia invited each Australian State netball association (n = 8) to participate in this study. Each State association invited all the coaches (n = 23), S&C coaches (n = 5) and physiotherapists (n = 19) working with their State 17/U & 19/U teams to participate. A minimum of four and a maximum of 10 participants were invited from each State. In total, 47 participants were invited to contribute to the study.

Netball Australia provided the State associations with study information and the link to the online platform. The State associations forwarded this information to participants via email. Participants provided informed consent to participate in the project the first time they registered on the Concept Systems Global MAX web platform. Ethics approval was obtained from the University of Canberra Committee for Ethics in Human Research (No 1551).

Before participating in their first CM activity, participants provided information about their role in netball, the age group they work with, their years of experience working with the State 17/U & 19/U teams, their total years of experience in netball, and their experience with the KNEE program.

After providing the participant information, participants were asked to complete the brainstorming activity. Two reminder emails were sent before this step was closed. All participants, even if they did not participate in the brainstorming, were emailed an invitation to participate in the next two tasks, statement sorting and rating. Two reminder emails were also sent before the sorting and rating tasks were closed. The CM data was collected over three weeks in March 2019, before the 17/U & 19/U 2019 Australian National Netball Championships (ANNC).

Concept mapping analysis

Standard CM data analysis techniques using the Concept Systems Global Max were applied to this study.[29] The first step involved constructing a similarity matrix based on the frequency with which each statement was sorted with every other statement by all participants. Multidimensional scaling was applied to the similarity matrix data to place each sorted statement as a separate point on a two-dimensional relational 'point map'. Hierarchical cluster analysis was then used to partition the statements on the point map into clusters of related statements based on participants' aggregated sorting data ('cluster maps').[28] Cluster maps were produced for a 4-cluster solution through to a 9-cluster solution to find the cluster level that retained the most useful detail between clusters while merging the clusters that logically belong together. Once the most appropriate cluster solution was subjectively determined, the research team reviewed every statement in each cluster and if a statement was considered to be a better conceptual fit in an adjacent cluster (i.e. the theme of an adjacent cluster more accurately and appropriately encompassed the idea underpinning the statement), it was reassigned to that cluster.[35] All reassignment decisions were guided by cross referencing back to the similarity matrix to check how frequently participants had grouped the statement being considered for reassignment with statements in adjacent clusters, and based on consensus among the research team.

Importance and difficulty rating descriptive statistics were calculated and used to generate a 'go-zone'[28] in which the mean importance rating for each statement was plotted along the x-axis and the mean difficulty rating for each statement was plotted along

the y-axis. Figure 1 demonstrates how the statements are plotted on the 'go-zone map'. The resulting scatterplot was divided into four quadrants using the all-statement mean of each rating as the axis. The top right quadrant is considered the 'go-zone' as it includes the most important and difficult challenges that should be prioritised to improve implementation of the KNEE program. A correlation coefficient was calculated to demonstrate the relationship between the importance and difficulty of a challenge.

Results

Participants

Thirty-nine of the 47 (83%) invited participants contributed CM data – 38 (97%) participants brainstormed ideas, 30 (77%) participants sorted statements, 30 (77%) participants rated importance of the challenge and 29 (74%) participants rated difficulty to overcome (see Supplementary Figure 1). Twenty-eight participants contributed data to all activities and seven contributed to only the brainstorming task. Characteristics of the 39 participants are summarised in Table 1.

Brainstorming: Challenges identified

Thirty-eight respondents generated 41 statements, which after synthesis and editing, yielded 46 individual statements (Table 2).

Sorting: Concept map

Figure 2 presents the cluster map developed from the multidimensional scaling and hierarchical cluster analysis. The distance between the points reflects how frequently participants grouped the statement together and considered as a proxy indicator of the degree of similarity between statements. For example, the statements most frequently grouped together were statement 8 (*'Optimal technique on knee program components not monitored'*) and statement 11 (*'Difficult to ensure technique is correct across all athletes and exercises'*), so they are very close to each other on the cluster map. Conversely, statement 33 (*'I modify it to suit our needs'*) was never grouped together with statement 23 (*'Lack of mobile access to videos to enable better correction of technique at point of training'*), therefore these statements are very far apart on the cluster map. The stress value, a measure of the degree to which the distances between points on the map are discrepant from the values in the input similarity matrix, was 0.268, which is similar to the average stress value of other CM projects[28] and indicates a good fit between the two dimensional point map and the original data as sorted by the participants.

Based on the authors' expert opinion, an eight-cluster map was selected as the best representation of the grouped data. The statements within each cluster, with the clusters organised from highest to lowest importance, and the eleven statements that were reassigned by authors to create a better conceptual fit, are presented in Table 2.

Rating: Perceived importance and difficulty

Table 2 provides the mean ratings of importance and difficulty for each of the 46 statements and for the eight clusters.

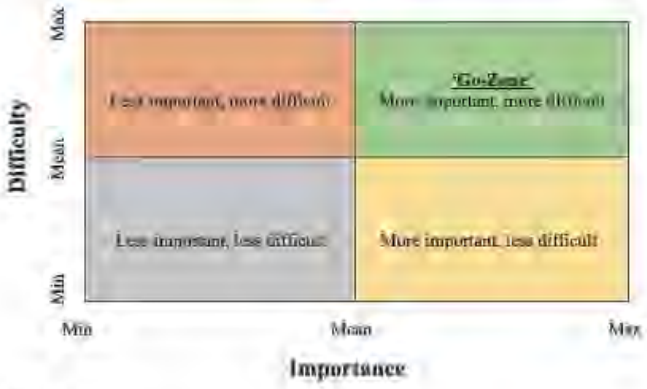

Figure 1. Go-zone quadrant descriptions.

Table 1. Participant characteristics.

Characteristics of participants (n = 39)	Overall n (%)	Brainstormed	Sorted	Rated importance	Rated difficulty
Gender					
Male	14 (36%)	13	11	11	11
Female	25 (64%)	25	19	19	18
Current role					
Physiotherapist	16 (41%)	16	14	15	14
Head coach	14 (36%)	14	11	10	10
S&C coach	5 (13%)	4	3	3	3
Assistant coach	3 (8%)	3	1	1	1
Other: Physio coordinator	1 (2%)	1	1	1	1
Age group					
17/U only	13 (33%)	13	10	10	10
19/U only	14 (36%)	14	10	10	9
17/U & 19/U	12 (31%)	11	10	10	10
17/U or 19/U experience					
This is my first year	9 (23%)	8	6	7	6
2–5 years	23 (59%)	23	19	19	18
5–10 years	7 (18%)	7	5	5	5
Netball experience					
<2 years	7 (18%)	6	5	6	5
3–5 years	7 (18%)	7	5	5	5
6–10 years	4 (10%)	4	4	4	4
>10 years	21 (54%)	21	16	15	15
KNEE experience					
Always use	12 (31%)	12	9	8	8
Frequent use	18 (46%)	18	13	14	13
Tried to use	5 (13%)	4	4	4	4
Never used	4 (10%)	4	4	4	4

Table 2. Statements generated during the concept mapping brainstorming process including the cluster in which each statement fits, mean importance and difficulty of overcoming ratings and go-zone graph quadrants for each statement.

		Mean rating		Go-zone quadrant[c]
		Importance[b]	Difficulty[b]	All statements
Cluster 1: Athlete engagement		**3.31**[a]	**2.48**[a]	
3*	Making sure athletes are committed to executing the KNEE program with correct technique.	4.43	2.93	1
2*	Making sure athletes are committed to executing the KNEE program warm up.	3.97	2.62	1
38	Athletes can sometimes be complacent in carrying the drills out because they lack the education behind the program.	3.43	2.59	1
31*	The girls sometimes go through it too quickly and don't hold the lands for long enough.	3.23	1.82	1
27	To ensure all aspects of the program are covered as the girls tend pick the aspects they like and not what is necessary.	2.50	2.34	1
28	Some of the athletes are still in the 'learning how to train' stage of development where they struggle with retention of new concepts including a specific warm up.	2.27	2.76	1

(continued)

Table 2. Continued.

		Mean rating		Go-zone quadrant [c]
		Importance[a]	Difficulty[b]	All statements
Cluster 2: Supervision/correction of technique		**3.03**[◇]	**2.67**[◇]	
19	Supervising the technique to make sure it is correct.	3.77	2.86	
45	Getting to all athletes in the time we are doing it – detecting and correcting and spending the time to do it correctly – landings and strength in particular.	3.63	3.50	
8	Optimal technique on knee program components not monitored.	3.53	2.52	
11	Difficult to ensure technique is correct across all athletes and exercises.	3.50	2.76	
18	Given the number of athletes it is hard to review all across all movements.	2.93	3.10	
1	Fidelity when I'm not overseeing the training (eg in club environments).	2.40	2.83	
23	Lack of mobile access to videos to enable better correction of technique at point of training.	1.47	1.10	
Cluster 3: Time constraints		**2.85**[◇]	**2.64**[◇]	
34	Having the time to provide group education so that the program is implemented as intended, and to improve adherence rates over the long-term.	3.73	2.69	
40	Lack of time to make sure they are completing the exercises correctly each time is challenging.	3.10	2.93	
46*	Covering all components – e.g. strength, agility etc.	3.10	3.00	
39	Time available to spend with each individual athlete to choose exercises that will benefit them specifically.	2.67	2.93	
37	Working out which parts to use as part of a restricted time warm up.	2.57	2.34	
24	Some coaches find it difficult to implement the program in the 1.5 training session they have.	1.90	2.00	
Cluster 4: Athlete technique		**2.70**[◇]	**2.64**[◇]	
12*	Since warm ups are completed as a group, may be difficult to ensure elements of the KNEE program are targeted at the appropriate difficulty level for the individual.	2.80	2.83	
17	Need to assess all athletes 1:1 to provide feedback that they can then implement when doing the knee program as part of the warm up.	2.73	2.93	
9	Optimal technique on knee program components not individualised.	2.57	2.17	
Cluster 5: Education		**2.56**[◇]	**2.16**[◇]	
22	Lack of coach/S&C/physio education contributes to limited athlete feedback about knee position/ technique.	3.17	2.34	
4	Lack of coach/physio/athlete understanding of intent required to get the most quality from the KNEE program warm up.	2.93	2.10	
29	Some difficulty convincing coaches in the multiple settings the girls train in of the value of it.	2.90	2.72	
13	KNEE program is not required because technique is targeted in the prehab/activation prior to their warm up so they have individual feedback on technique.	1.23	1.48	

(continued)

Table 2. Continued.

		Mean rating		Go-zone quadrant[a]
		Importance[b]	*Difficulty*[b]	*All statements*
Cluster 6: Support staff resourcing		**2.46**[c]	**2.64**[c]	
41	Not having supervised gym sessions (17/U and 19/U) to be able to implement more strength/power based aspects of the program.	3.00	2.97	1
43	Education is presented to coaches and S&C regarding the KNEE program but physio is only covered 2 hours/week to cover both 17s and 19s training. Never get to see whether it's implemented or how well.	2.80	3.11	1
44*	Implementing it as part of the training session as I only work with the athletes once a week.	2.72	2.83	1
7*	Lack of time with athletes at the beginning of campaign to implement within warm up drills & gym program.	2.70	2.38	2
15	Having the time to properly implement it with careful supervision of technique while also attending to other roles required of myself as physiotherapist.	2.67	2.90	1
30	As physio I only get a maximum of 2-3 hours a week with state teams and I am unable to ensure it is implemented throughout other sessions.	2.63	2.76	1
42*	Budget restraints meaning I only can supervise some aspects of the program in the limited time I get.	2.40	3.07	3
35	I am not present frequently enough to determine if the athletes are consistent with the program.	2.37	2.69	3
5	S&C coaches are not always present at training sessions so cannot always be delivered through them.	1.83	1.59	4
25	No access to S&C sessions.	1.63	2.14	4
Cluster 7: Program flexibility/adaptability		**2.02**[c]	**1.85**[c]	
14	Keeping it interesting and fresh for the athletes.	2.30	1.97	4
20	Keeping it interesting with variety for the players.	2.27	2.07	4
8*	Lack of individuality of knee program with respect to individual athlete movement screening.	2.07	2.41	3
16	To change it up enough so that it doesn't get boring but ensure it is covering and achieving what it needs to.	1.97	2.10	4
33	I modify it to suit our needs.	1.97	1.21	4
18	Keeping it functional enough that coaches remain happy.	1.80	1.72	4
32	I use ideas from the program, but don't use it specifically as I draw on personal experiences and ideas.	1.79	1.45	4
Cluster 8: Coach/support staff prioritisation		**1.95**[c]	**1.81**[c]	
10	Athletes emphasis when coming for training sessions is to optimize time spent as a team on court.	2.50	2.17	4
21	Incorporating ball work so it does not take up too much time.	2.13	1.79	4
36	As the Physiotherapist it's not my role to go through warm ups etc. with the team.	1.23	1.48	4
For all statements		**2.63**[c]	**2.41**[c]	

Figure 2. Eight-cluster map of challenges for netball coaches, strength & conditioning coaches and physiotherapists of State 17U & 19U athletes implementing the KNEE program.

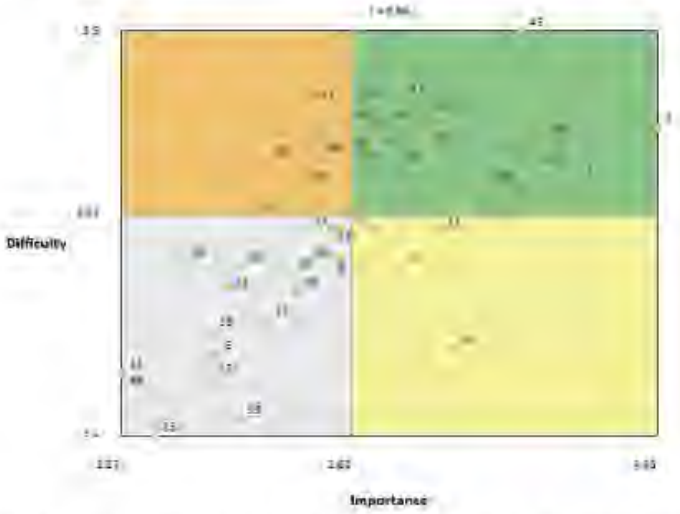

Figure 3. Go-Zone of challenges for netball coaches, strength & conditioning coaches and physiotherapists of State 17U & 19U athletes implementing the KNEE program.

'Go-zone': Challenges to be prioritised

Figure 3 presents the go-zone for all 46 statements. The 'go-zone' quadrant (top right) contains the statements (n = 19) that received above average ratings on both importance and difficulty. Statements in the go-zone quadrant were rated as the most important and difficult challenges to overcome. As such, it is anticipated that they will require the most support to address. The bottom right quadrant includes statements (n = 4) that were also rated relatively more important but less difficult to overcome and could also be considered as a starting point to achieve early intervention success with minimal resources. The top and bottom left quadrants were rated as less important so the challenges in these two quadrants should be a lower priority. The Pearson Product Moment Correlation coefficient for the go-zone graph indicates moderate correlation between 'Importance' and 'Difficulty' ($r = 0.66$).[36]

Discussion

Ankle sprains and knee injuries have the highest injury incidence in pre-elite netball so improving compliance to the KNEE program in this population is a priority for Netball Australia. This study has identified the challenges encountered by netball coaches, S&C coaches and physiotherapists when implementing the KNEE program in a pre-elite population. The following eight clusters of challenges emerged from this

study: 'athlete engagement', 'supervision and correction of technique', 'time constraints', 'athlete technique', 'education', 'support staff resourcing', 'program flexibility and adaptability' and 'coach and support staff prioritisation'. This highlights that barriers to implementing the KNEE program are complex and multi-factorial, requiring the application of a well-recognised implementation sciences framework[37] to address these barriers.

According to the Active Implementation Research Network,[37] the implementation drivers framework (IDF) can improve implementation of evidence-based interventions. The IDF consists of three sets of implementation drivers: competency drivers (e.g., staff selection, training and performance evaluation), organisational drivers (e.g., systems interventions and facilitative administration) and leadership drivers (e.g., operational and strategic leadership, i.e., planning, procedures, culture, vision, policies and resource allocation). Application of these drivers can facilitate long-term, high-fidelity intervention implementation. Implementing injury prevention strategies in sport is complex[38] and there has been limited use of the IDF in sport,[39] although it has been advocated for[40,41] and is widely recognised in implementation science.[42] The authors have used the IDF to inform strategies to overcome the go-zone challenges within each cluster identified within this study.

Focusing on competency drivers can facilitate implementation of the KNEE program by ensuring coaches and support staff have the necessary knowledge, skills and attitude to successfully implement this injury prevention intervention.[37] Improving competency can help overcome the go-zone challenges identified in the 'athlete engagement', 'supervision and correction of technique', 'athlete technique', 'time constraints' and 'education' clusters (see Table 2). Staff selection is one example of driving competency to identify coaches and support staff that are ready, willing and able to use the KNEE program. If a suitable candidate is identified but they lack KNEE experience, the selection process should assess whether the candidate's philosophy, values and readiness to learn are conducive to learning how to implement the KNEE program in a timely, engaging way with high fidelity. In addition to staff selection, staff training is another competency driver that can be used to educate staff about current injury rates, what the KNEE program is, how it can be adapted and details of its efficacy.[43] Skills can also be developed to assess exercise technique and provide feedback to athletes in ways that lead to improved technique.[44,45] Staff training can also educate coaches on how to efficiently integrate the KNEE program into the given time allocated for team training.[46]

The go-zone challenges within the 'supervision and correction of technique', 'athlete technique', 'athlete engagement' and 'time constraints' (see Table 2) can be addressed with organisation drivers. Organisation drivers facilitate changes in the operation of an organisation to support its staff to change their behaviour to deliver an innovation such as the KNEE program.[37] Facilitative administration is an example of an organisation driver to support the staff's use of the KNEE program such as timely access to staff training or completing staff selection well in advance of pre-season training commencing. Additionally, ensuring there is enough 'court time' available to complete the KNEE program to address the challenges in the 'time constraints' cluster is an example of facilitative administration.[47] Decision support data system is another example of an organisation driver which involves using data to support decision making. Collecting and communicating injury and intervention effectiveness data to athletes, parents and coaches[48] could improve 'athlete engagement' and 'coach and support staff prioritisation'.

Leadership is key to successful implementation.[49] Leadership drivers involve early identification and engagement of individuals already in executive leadership roles who can make informed decisions to implement the KNEE program and agree to fully participate in the implementation process.[37] This can include facilitation of role modelling where a peer-leader led education session is arranged to enhance athlete knowledge of and attitudes towards the KNEE program.[50] Perhaps appointing a highly respected individual to 'train the trainers' can be used to develop high levels of competency and demonstrate how the KNEE program can be implemented within identified constraints such as time.[51] Alternatively, increasing support staff resourcing to deliver the KNEE program may be the best solution.[52] These examples of leadership are ways in which the go-zone challenges in 'athlete engagement', 'time constraints' and 'support staff resourcing' clusters (see Table 2) can be mitigated.

Now that the most important and most difficult challenges for implementing the KNEE program have been identified within the go-zone, Intervention Mapping (IM)[53] can be used to plan strategies to facilitate the adoption, implementation and sustainability of the KNEE program. Intervention Mapping is a six-step process, starting with problem identification and finishing with problem mitigation.[54] Step 5 of IM focuses specifically on planning the implementation of an evidence-based intervention such as the KNEE program and has been successfully used to improve the implementation of injury prevention programs in community sport.[55,56] Applying this process will require Netball Australia to create a planning group of

athletes, coaches, support staff and organisation leaders to collaboratively identify desired outcomes and performance objectives for the identified challenges and develop change objectives before designing implementation interventions.

It is important that the strengths and limitations of this study are acknowledged and considered when interpreting its findings. The use of concept mapping is a strength as it is a real-world practical consultative method[28] that involves online qualitative structured group data collection from people who are spread across the country and then applies quantitative tools to develop visual maps representing the groups ideas. Thus, we learn from participants individual experiences and gain valuable quantitative data to inform decision making. A limitation of this study is that athletes were not invited to participate due to not wanting to impact their preparations for the 2019 ANNC. Athlete motivation to participate[57] in the KNEE program is crucial for program success. If athletes had been included in this study, they may have contributed and prioritised different ideas than coaches and staff, (e.g., 'Program flexibility and adaptability') which would have altered our study outcomes. Athlete insight as end-users is valuable and should be included in future research on KNEE program implementation.

Conclusion

This study identified the following challenges as the most important and difficult to overcome when implementing the Netball Australia KNEE program in 17/U and 19/U State teams: 'athlete engagement', 'supervision and correction of technique', 'time constraints', 'athlete technique', 'education' and 'support staff resourcing'. There is the potential to successfully address these challenges using the implementation driver's framework.[35,38] Implementation drivers to consider, include education for athletes, coaches, and organisation leaders to highlight the value of the KNEE program for all involved and provide guidance for program delivery with high fidelity and engagement. Changing position descriptions and performance assessment policy for coaches and support staff and changing the KNEE program structure are also strategies worth trialling. The next step is to gain the athletes perspective on barriers to performing the KNEE program and then applying a systematic approach to implementation planning using a recognised process such as IM Step 5.[55,56]

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Supplemental Material

Supplemental material for this article is available online.

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Chapter 6 Evaluating effectiveness of preventative measures in an implementation context (TRIPP 6)

Paper submitted for publication

This chapter is based on a paper that has been submitted for publication in the journal Translational Sports Medicine. Ankle sprains, low back pain and foot blisters were the most frequent injuries reported at the 2018 17/U & 19/U ANNC, while ACL ruptures and concussion resulted in the greatest sports incapacity. Prevention strategies such as the KNEE program are in place to address the prevalence of ankle sprains and ACL rupture. Netball Australia is addressing the incidence of concussions within its related policy and procedures. Strength and conditioning coaches and physiotherapists are addressing the incidence of lower back pain at an individual level. However, foot blister prevention has never been prioritised at this level. The current study assessed the effectiveness of a foot blister prevention strategy within the real-world setting of the 2019 17/U & 19/U ANNC. Additionally, medical attention and self-report injury surveillance conducted at the 2018 17/U & 19/U ANNC was repeated at the 2019 17/U & 19/U ANNC, resulting in improved understanding of the pre-elite netball athlete injury profile.

Co-authors' declaration

Declaration of Co-Authored Publications

UNIVERSITY OF CANBERRA

For use in theses which include co-authored publications. This declaration must be completed for each co-authored publication and to be placed at the start of the thesis chapter in which the publication appears, or as a preface to the thesis.

Declaration for Thesis Chapter Six

Publication: "Injury surveillance at the 17/U & 19/U Australian National Netball Championships and the effect of a foot blister prevention intervention"

DECLARATION BY CANDIDATE

In the case of Chapter Four, the nature and extent of my contribution to the work was the following:

Nature of Contribution	Extent of Contributions (%)
Conception and design of the research proposal	80%
Data collection	50%
Analysis and interpretation of the findings	70%
Writing the paper and critical appraisal of content	70%
Corresponding author for journal communication and publication peer-review process.	100%

The following co-authors contributed to the work:

Name	Nature of Contribution	Contributor is also a UC student (Yes/No)
Gordon Waddington	Conception and design of the research proposal Data collection Analysis and interpretation of the findings Writing the paper and critical appraisal of content	No
Alanna Antcliff	Conception and design of the research proposal Analysis and interpretation of the findings	No
Phil Newman	Writing the paper and critical appraisal of content	No
Juanita Weissensteiner	Writing the paper and critical appraisal of content	No
Liam Toohey	Analysis and interpretation of the findings	No
Ruth Fazakerley	Design of intervention	No
Laura Piromalli	Conception and design of the research proposal Analysis and interpretation of the findings	No
Theo Niyosenga	Analysis and interpretation of the findings	No
Michael Drew	Conception and design of the research proposal Analysis and interpretation of the findings Writing the paper and critical appraisal of content	No

Candidate's Signature

17/09/2021

Date

Declaration of Co-Authored Publications

DECLARATION BY CO-AUTHORS

The undersigned hereby certify that:

(1) the above declaration correctly reflects the nature and extent of the candidate's contribution to this work, and the nature of the contribution of each of the co-authors.
(2) they meet the criteria for authorship in that they have participated in the conception, execution, or interpretation, of at least that part of the publication in their field of expertise;
(3) they take public responsibility for their part of the publication, except for the responsible author who accepts overall responsibility for the publication;
(4) there are no other authors of the publication according to these criteria;
(5) potential conflicts of interest have been disclosed to (a) granting bodies, (b) the editor or publisher of journals or other publications, and (c) the head of the responsible academic unit; and
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Location(s):	Australian Institute of Sport

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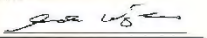
Signed: 
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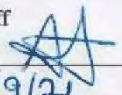
Signed: 
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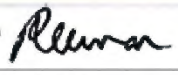
Signed: 
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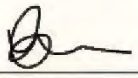
Signed: 
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Injury surveillance at the 17/U & 19/U Australian National Netball Championships and the effect of a foot blister prevention intervention

Abstract

Objective: Surveillance of injury/illness at the 2019 17/U & 19/U Australian Netball National Championships (ANNC) and evaluation of the effectiveness of a foot blister prevention strategy.

Design: Prospective observational cohort study with intervention.

Methods: One hundred and ninety-two athletes were observed during a six-day tournament. Medical attention injuries were recorded prospectively by physiotherapists and athlete self-reported injury data was collected. Additionally, a foot blister prevention strategy was applied six weeks prior to tournament commencement.

Results: Ninety-five medical attention injuries were sustained by 73 athletes, at an incidence rate of 82.5 injuries/1000 player competition hours. Ankle sprains (n=16) and lumbar pain (n=12) had the highest incidence of medical attention injuries. Thirty per cent of athletes started the tournament with a self-reported injury/illness. Twelve sports incapacity injuries were recorded, with concussion (n=5) and ACL rupture (n=4) the most frequent. Team physiotherapists recorded eight foot blisters in 2019 and eleven foot blisters in 2018, this difference was not statistically significant.

Conclusions: Ankle sprains were the highest medical attention injury recorded in pre-elite netball athletes. This has not changed over the past 30 years, indicating current ankle sprain prevention strategies are not effective. Our foot blister prevention strategy was not effective for preventing foot blisters in pre-elite netball athletes.

Keywords: Athletic injuries; Surveillance; Sports medicine; Sprains and strains; Foot blisters; Pre-elite netball population

Introduction

Netball is the most popular team sport in Australia for women and girls, but participation decreases after the age of 15 with poor health or injury the second greatest reason for drop-out.[118] Australia has remained on top of the world netball rankings over the last five years.[119] For sustained success, Netball Australia seeks to continue junior player development, with a critical component focusing on maintaining the health of athletes through injury and illness prevention strategies.

Injury surveillance has previously been conducted at the 2018 17/U & 19/U Australian Netball National Championships (ANNC).[114] These championships are an opportunity for each Australian state to compete against the others and for Australian national squads to be selected. Ankle sprains, low back pain and foot blisters were the most frequent injuries reported, with anterior cruciate ligament (ACL) ruptures the most severe, at the 2018 ANNC.[114] Ankle sprains and knee injuries have consistently had the highest incidence rate in netball over the past 30 years.[56-59] Historical prevention programs targeting ankle and knee injuries have previously been implemented;[74,75] however, foot blisters have not yet been targeted.

Foot blisters are a common occurrence in netball.[55,58,114] Despite this, there is no evidence of foot blister prevention strategy implementation in the netball population. Of the many netball injury surveillance studies,[54] only two have reported foot blister injury rates.[55,58] Hopper, in 1986 recorded 45 foot blisters (28.5%) across a 14-week netball season,[55] and Hume & Steele in 2000 recorded 2 foot blisters (2%) during a three-day tournament.[58] At the 2018 17/U & 19/U ANNC, foot blisters continued to be problematic, causing 11 athletes to require medical attention and resulting in sports incapacity for two athletes.[114] Foot blister prevention studies have previously been conducted with military personnel and endurance runners.[120,121] It is generally accepted that foot blisters can be easily prevented with correct footwear and foot hygiene.[122,123] We tested this hypothesis by implementing a prevention strategy at the 2019 17/U & 19/U ANNC.

The objectives of this study are to:

1) Describe the type and mechanism of injuries that occurred across the six-day 2019 17/U & 19/U ANNC and during the four weeks following the tournament.
2) Compare injury rates between the 2018 and 2019 17/U and 19/U ANNC.
3) Evaluate the effectiveness of a blister prevention strategy for reducing the number of foot blisters reported at the 2019 ANNC compared to the 2018 ANNC.

Methods

Participants & Design

All athletes (n=192; 17/U athletes = 96, 19/U athletes = 96) competing at the 17/U & 19/U ANNC were invited to participate in the present study. Sixteen female teams competed in the six-day tournament (11–16 April 2019). Each team played nine matches, with two matches played on days one, three and four, while one match was played on days two, five and six. A total of 144 matches were played, with each match consisting of ten-minute quarters. Athletes were not exposed to training during the competition due to the congested match schedule. The methods for the 2018 17/U & 19/U ANNC injury surveillance collection have previously been published[114] and were repeated in 2019. The Strengthening the Reporting of Observational studies in Epidemiology in Sports Injury and Illness Surveillance (STROBE-SIIS) was followed.[47] Ethics approval was obtained from the Australian Institute of Sport Human Research Ethics Committee (Approval number: 20180404). All participants or their parents/guardians provided consent via their individual online Athlete Management System (AMS; Smartabase, Fusion Sport, Brisbane, Australia) account.

Intervention strategy

Six weeks prior to the ANNC, every athlete received a foot blister prevention and management pack, frequently used by the Australian Institute of Sport Medical Department, and an advice sheet (Appendix 17) developed by one of the authors (RF). Each team physiotherapist was asked to present the information in the advice sheet to their athletes while distributing the prevention packs. Athletes were also encouraged to not wear new netball shoes within four weeks of the tournament start.

Outcome measures

Injuries were defined in three ways: 1) self-reported, 2) medical attention and 3) sports incapacity. Athlete self-reported injuries were defined as sensations that are interpreted by an athlete as being indicators of abnormal body function.[124] All athletes were asked to complete the Oslo Sports Trauma Research Centre Questionnaire on Health Problems (OSTRC-H)[20,125] via their AMS accounts at four time points: 1) the start of the tournament, 2) end of the tournament, 3) one week post-tournament and 4) four weeks post-tournament. This questionnaire asks the athlete to report any injuries or illnesses experienced in the past week in terms of participation, training volume, effect on performance and symptoms. The questionnaire allows for multiple injuries and illnesses to be reported.

A medical attention injury was defined as loss or abnormality of bodily structure or functioning that following examination is diagnosed by a clinical professional as a medically recognised injury.[124] Team physiotherapists were asked to record all medical attention injuries using a standardised injury record form within the AMS. A four-character Orchard Sports Injury Classification System 10 (OSICS-10.1)[126] injury diagnosis code was assigned prospectively by each team physiotherapist. The lead author (ES) met with all team physiotherapists prior to the tournament to explain the injury record system and clarify any areas of uncertainty. All physiotherapists were encouraged to complete each injury record on the day of injury. Sports incapacity injuries were defined as an injury that required an athlete to miss any duration of match play during the tournament or where the athlete reported a reduction in participation as assessed by the OSTRC-H.[124]

Exposure was quantified according to the 'athlete participation' method, which defines participants as those that are on the game roster whether they played or not.[127] The number of athletes per team (n=12) was multiplied by the number of teams (total=16, 17/U=8, 19/U=8), number of matches (n=9) and the number of minutes per match (n=40) and then divided by the number of minutes per hour (n=60). This resulted in a total of 1,152 player competition hours, or 576 player competition hours for each of the 17/U or 19/U athlete cohorts.

Statistical analysis

Descriptive analysis was performed for the 17/U and 19/U athlete cohorts at the 2019 ANNC. The differences between age groups for medical attention injuries (including foot blisters), sports incapacity injuries and injury classification were measured by calculating incidence rate ratios (IRR) and Fisher's exact test to test for significance. ANNC competition years were also compared by calculating IRR for medical attention injuries and specific injury diagnoses. Injury incidence rates were calculated using the formula: number of new injuries/number of exposures per 1000h.[40] Incidence rate ratios were also calculated to compare age groups and ANNC competition years. Analysis of the OSTRC-H questionnaire outcomes across the four dates completed by the 2019 cohort utilised the McNemar chi-square test, as this involved comparison of non-independent groups (repeated sampling). Comparison of the OSTRC-H outcomes between the 2018 and 2019 ANNC cohorts was performed using the Pearson chi-square test.

Results

Medical attention and sports incapacity injuries (including foot blisters)

Ninety-five medical attention injuries were sustained by 73 athletes over a six-day period, at an incidence rate of 82.5 injuries/1000 player competition hours. Sports incapacity incidence rate was 10.4/1000 player competition hours. There was no significant difference between 17/U & 19/U medical attention injury rates (17/U, n=47; 19/U, n=48; IRR=0.98; 95% CI: 0.64–1.50; p=0.92). Lateral ankle ligament sprains (n=16, 16.8%), lumbar pain (n=12, 12.6%) and foot blisters (n=8, 8.4%) were the most frequently recorded injuries. There were 12 (12.6% of total injuries) sports incapacity injuries recorded, with concussion (n=5) and ACL rupture (n=4) the most common. None of the foot blisters resulted in sports incapacity. There were twice as many 17/U sports incapacity injuries compared to 19/U sports incapacity injuries; however, this was not statistically significant (17/U, n=8, 8.4%; 19/U, n=4, 4.2%; IRR=2.00; 95% CI: 0.54–9.08; p=0.27). Ninety-five per cent (n=90) of injuries were classified as new injuries and occurred 18 times more frequently than recurrent injuries (n=5, 5%; IRR=18.00; 95% CI: 7.43–56.78, p<0.01). Details of the mechanism of injury, injury onset and classification of injury according to each body area are outlined in Table 1.

2018 versus 2019 ANNC

Compared to the 2018 ANNC[114] results, there was no difference in total medical attention injuries in 2019 (2018, n = 103; 2019, n = 95; IRR=1.08; 95% CI: 0.81–1.45; p=0.57). There were also similar number of 19/U injuries (2018 19/U, n=64; 2019 19/U, n=48; IRR=1.33; 95% CI: 0.90–1.98; p<0.13) and 17/U injuries across both years (2018 17/U, n=39; 2019 17/U, n=47; IRR=0.83, 95% CI: 0.53–1.30; p=0.39). No reduction in foot blisters was observed (2018, n=11; 2019, n=8; IRR=1.38; 95% CI: 0.50–3.94; p=0.50). There were also similar frequency of ankle sprains (2018, n=14; 2019, n=16; IRR=0.88; 95% CI: 0.40–1.91; p=0.72), lumbar pain (2018, n=10; 2019, n=12; IRR=0.84; 95% CI: 0.32–2.10; p=0.68), ACL ruptures (2018, n=3; 2019, n=4; IRR=0.75; 95% CI: 0.11–4.43, p=0.73) and concussion (2018, n=3; 2019, n=5; IRR 0.60; 95% CI: 0.09–3.08, p=0.51).

Health problems questionnaire

The response rate for the four OSTRC-H questionnaires (1: at the start of the tournament, 2: end of the tournament, 3: one-week post-tournament, and 4: four weeks post-tournament) was greater in 2019 (93%, 99%, 78% and 74% respectively) than in 2018 (90%, 76%, 41% and 34% respectively). Of the 175 athletes that completed the first and second OSTRC-H in 2019, 30% (n=53) started the tournament with a self-reported injury/illness. There was a significant increase in the number of athletes (n=74, 42%) who self-reported an injury/illness at the end of the tournament compared to the start (χ^2=11.76, p<0.01; OR= 2.11; 95% CI: 1.19–3.85). Ten (7% of respondents) of these athletes could not participate at all four weeks following the 2019 ANNC, whereas three athletes (2% of respondents) reported not being able to participate in netball during the week prior to the 2019 ANNC.

Forty athletes (28% of respondents) in 2019 and 22 athletes (34% of respondents) in 2018 reported training at a reduced volume four weeks following the tournament due to self-reported injury/illness (χ^2=0.69, p=0.41). Sixty-nine athletes (36% of respondents) in 2019 and 55 athletes (38% of respondents) in 2018 thought their performance was affected by injury/illness during the tournament (χ^2=0.07, p=0.80).

Discussion

Injury surveillance has now been prospectively investigated across two years of the 17/U & 19/U ANNC. The combined 17/U and 19/U injury incidence rate was lower in 2019 (82.5/1000 player hours) compared to 2018 (89.4/1000 player hours), but this was not statistically significant.[114] Lateral ankle ligament sprains, lumbar pain and foot blisters were the most frequently recorded injuries in 2018 and 2019.[114] The number of sports incapacity injuries fell from 22 in 2018[114] to 12 in 2019; however, the number of ACL ruptures increased by one (2018, n=3; 2019, n=4) and concussions slightly elevated from three to five.[114] Further prevention strategies are indicated to address these significant ongoing health issues.

The International Olympic Committee (IOC) consensus statement on youth athletic development states: 'No youth athlete should compete – or train or practice in a way that loads the affected injured area, interfering with or delaying recovery – when in pain or not completely rehabilitated and recovered from an illness or injury'.[4] Thirty-one per cent of athletes started the tournament with a self-reported injury/illness, an increase from 27% in 2018.[114] Prior to these two studies, the OSTRC-H has not been utilised to record injury data for pre-elite athletes competing in a tournament, making it difficult to draw conclusions about whether these figures are common in this population. Nevertheless, our results indicate that a concerted effort needs to be made to heed the advice of the IOC[4] and improve the health of athletes attending the tournament. Improved awareness of pre-elite injury prevention and management needs to occur across the system, including state bodies, clubs, coaches, managers, parents and athletes.

There was no meaningful reduction in foot blisters in 2019 (n=8, 8.4%) compared to 2018 (n=11, 10.7%). There was no incidence of sports incapacity due to foot blisters in 2019. A higher frequency of foot blisters was recorded at the 2018 & 2019 17/U & 19/U ANNC compared to previously reported injury data from a three-day New South Wales netball tournament in 1995 (n=2, 2% of total injuries).[58] It is difficult to claim a reduction of three blisters across six days and 192 athletes at the 2019 17/U & 19/U ANNC is of clinical significance; however, it is promising to observe a reduction in this injury rather than an increase. This strategy could be improved by involving the team physiotherapists in the research project earlier to increase their engagement and highlight the important role they play in

educating athletes about foot blister prevention. Continuing to implement this simple foot blister prevention strategy is advised.

There were two additional concussions at the 2019 17/U & 19/U ANNC (n=3) compared to the 2018 17/U & 19/U ANNC (n=5) but this difference was not statistically significant. Concussion incidence appears to have increased over the past 20 years. In 1998, Finch et al.[115] reported a frequency of 1.6% (n=4) over two consecutive five-month seasons and in 2014, there was one concussion recorded from 154 netball injuries presenting to an emergency department across a 2-year period.[128] Finch et. al.[129] reported an 8% annual increase in concussions sustained by netball athletes from 2002–03 to 2010–11. Possible explanations for this apparent increase in concussions are that historically they were not recognised and diagnosed, or that changes in game style over time mean that more collisions now occur in netball,[130,131] resulting in more concussions. Improving concussion injury surveillance and understanding mechanisms of injury are important steps towards preventing concussion and should be prioritised, as it is an injury that results in sports incapacity and can cause long-term sequelae.

Approximately one-third of athletes were training at a reduced volume due to an injury or illness following the 2018 and 2019 17/U & 19/U ANNC. In 2018 and 2019, five (8%) and ten athletes (7%) respectively could not participate at all, four weeks post tournament. At the start of the tournament, two (1%) athletes in 2018 and three (2%) athletes in 2019 could not participate in the week prior to the tournament. Athletes are required to play nine matches in six days at possibly a higher intensity than they would normally play. Preparation for this workload is very difficult when these athletes have other competing commitments such as school, university or work.[14,132] A spike in training load can increase risk of injury or illness for the following four weeks.[133] This data warrants a review of the 17/U & 19/U ANNC format – perhaps a system where teams are divided into two pools to limit the number of fixtures could be considered to reduce health consequences. Additionally, awareness and utilisation of recovery modalities[134,135] during this multiday tournament could be reviewed.

Two injury surveillance methods, athlete self-report and medical attention, were introduced in 2018 at the 17/U & 19/U ANNC and repeated in 2019. The athlete self-report response rate improved to be above 70% across all four OSTRC-H collection periods in 2019, compared to 2018[114] when the response

rate was below 50% for the two post-tournament OSTRC-H. There were also fewer missing data points for medical attention injuries in the second year of injury surveillance. For example, in 2018, 32 (31%) injury records did not include mechanism of injury data; in 2019, this decreased to 10 (11%) incomplete injury records. Establishing quality injury surveillance takes time and commitment by all personnel working within high-performance sport and is a critical component of injury prevention. We were able to implement injury surveillance across two 17/U & 19/U ANNC due to the strong support received from Netball Australia, highlighting the critical role National Sporting Organisations (NSOs) play in injury prevention. Our method for obtaining injury data from a pre-elite level national tournament is a good example of how other NSOs may also employ injury surveillance in their pre-elite populations at similar events.

We conducted a prospective intervention cohort study and compared results to a study conducted one year earlier.[114] Several limitations of this study are apparent. Firstly, there was no monitoring to ensure all athletes received their blister prevention packs, read their advice sheets, or followed the 'no new shoe' guidelines. This was due to the difficulties in measuring reach and adoption in a decentralised system and the inability of the research team to have direct contact with the athletes prior to the competition. In future, fidelity of the foot blister prevention strategy could be checked by researchers at the start of the tournament when athletes are asked to complete their first HPQ. Secondly, employing the OSTRC-H questionnaire potentially introduces self-reporting bias.

Conclusion

A high number of medical attention injuries (n=95) occurred at the 2019 17/U & 19/U ANNC. Ankle sprains are the most frequent medical attention injury in pre-elite netball athletes. This has not changed over the past 30 years, indicating current injury prevention interventions for ankle sprain are not effective. The foot blister prevention strategy trialled in this study did not result in a statistically significant reduction in foot blisters. Ongoing injury prevention work is required to not only reduce the number of foot blisters but also the overall number of injuries and number of significant injuries such as ankle sprain, ACL rupture and concussion.

Practical implications

- Introduction of a foot blister prevention advice sheet and pack did not result in fewer foot blisters at a six-day netball tournament. Greater attention needs to be focussed on the implementation process.
- Prevention of ankle sprains, ACL ruptures and concussion must remain a priority in pre-elite netball athletes.
- We must heed the advice of the IOC and stop our youth athletes from competing or training when injured or ill.

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Tables

Table 1: Mechanism of injury, classification and onset for each body area

	Body area										
	Ankle	Foot	Trunk †	Lower leg	Head & neck	Knee	Wrist, hand & fingers	Hip & groin	Upper limb ǂ	Thigh	Total
Total (n=)	24	14	16	8	8	9	5	2	4	5	95
Mechanism											
Accident/other	0	0	1	0	0	0	1	0	0	0	2
Catching	0	0	0	0	0	0	4	0	0	0	4
Change of direction	2	0	0	0	0	0	0	0	0	0	2
Collision	1	0	0	2	5	1	0	0	2	4	15
Contested landing	4	0	1	0	1	2	0	0	0	0	8
Jumping	1	0	0	1	0	1	0	0	0	0	3
Land on another	7	0	0	0	0	0	0	0	0	0	7
Non-contested landing	0	0	0	0	0	4	0	0	0	0	2
No specific incident	5	13	10	5	0	0	0	2	1	1	37
Missing	3	0	3	0	2	1	0	0	1	0	10
Classification											
New injury	23	14	14	7	8	8	5	2	4	5	90
Recurrent injury	1	0	2	1	0	1	0	0	0	0	5
Onset											
Trauma	18	0	1	2	7	7	5	0	2	4	46
Overuse	5	9	12	5	0	2	0	2	2	1	38
Other	1	5	3	1	1	0	0	0	0	0	11

† Thoracic and Lumbar spine; ǂ Shoulder, Elbow & Forearm

Chapter 7 Discussion and conclusion

Thesis summary

The primary objective of this sequence of doctoral studies was to apply a holistic strategy to prevent injuries in pre-elite athletes, using netball as an exemplar sport. To achieve this, we collaborated with Netball Australia. There are many stakeholders that influence outcomes for pre-elite athletes, and there are many injury prevention components to consider. Most organisations will already have established injury prevention strategies; therefore, it is important for these strategies to be considered when planning for future injury prevention interventions. Netball Australia had already started collecting injury data at the 17/U & 19/U ANNC, developed the KNEE program and established an ankle taping policy. Therefore, any interventions must take into consideration the established work within any organisation.

The major contribution of this work was to demonstrate how the process of injury prevention can only be achieved when researchers, practitioners, coaches, athletes and administrative staff work collaboratively. This has been demonstrated in other sports such as Norwegian female handball,[73] New Zealand rugby union[136] and Swiss amateur football.[137] We have worked collaboratively with Netball Australia to establish their pre-elite injury profile and progress the development and implementation of injury prevention interventions to reduce injury incidence in the pre-elite population. The lessons gained in this process have influenced the research studies included in this thesis and the thesis discussion.

Firstly, a multidisciplinary approach was used to achieve good quality injury surveillance, aetiology and mechanisms of injury, as per TRIPP Stages 1 and 2. Across a six-day tournament, 103 injuries were sustained by 80 athletes. The most frequent injuries were lateral ankle sprain, foot blisters and lumbar pain. Following the injury surveillance, a thorough systematic review was conducted as part of TRIPP Stage 3 to inform potential injury prevention intervention strategies. Eleven articles met the inclusion criteria of a pre-elite population competing in an Olympic or professional sport investigating interventions for any injury at any body site. There is limited evidence from level 2 and 3 studies

suggesting exercise and psychology interventions may prevent injury in pre-elite athletes. There were no studies meeting the criteria of low risk of bias.

These first two studies then directed the approach of the remaining studies. Regular prophylactic ankle taping was in place for the athletes competing at the 17/U & 19/U ANNC but there was limited recent evidence supporting this intervention. Discussion with Netball Australia and relevant ethics committees determined that removing a preventative action to assess efficacy was not ethical, noting it would be the best scientific approach. Therefore, ankle taping was scientifically evaluated under 'ideal conditions' according to TRIPP Stage 4 to demonstrate that proprioception improves immediately after application; And that it is maintained throughout a netball session regardless of whether it is applied by a Sport and Exercise Physiotherapist (SEP) or self-applied.

Concept mapping (CM) was used to fulfill TRIPP Stage 5 to improve implementation of Netball Australia's KNEE program. The coaches, physiotherapists, and strength and conditioning coaches attending the 2019 17/U & 19/U ANNC were consulted to gain a better understanding of the challenges to implementing the KNEE program. This will help guide implementation strategies in the future.

Finally, TRIPP Stage 6 was applied by assessing the effectiveness of a foot blister prevention strategy at the 2019 17/U & 19/U ANNC. Additionally, medical attention and self-report injury surveillance conducted at the 2018 17/U & 19/U ANNC were repeated at the 2019 17/U & 19/U ANNC.

We attempted to apply a generalisable approach to sport injury prevention. However, when working with established sports such as netball, who have established policy and procedure to prevent injuries, we had to be flexible with our study design. Working in collaboration with our end user, in this case Netball Australia, we prioritised the research questions they needed to be answered rather than what the research community thought should be answered. A strength of this thesis is the diversity of research methodology used to add value for the target population of netball. This is a parallel thesis rather than a series thesis to achieve a pragmatic approach to research.

Focus of thesis

The primary objective of this PhD was to develop and implement a system that will prevent injuries in pre-elite athletes, using netball as an exemplar sport. To achieve this, we collaborated with Netball Australia and attempted to apply the TRIPP framework with their pre-elite athletes. We established injury surveillance methods, reviewed current injury prevention strategies in the pre-elite setting, created supporting evidence and determined barriers for implementation of current injury prevention strategies and implemented a foot blister prevention strategy. This work will inform our strategies in the future for injury prevention in pre-elite athletic populations.

Summary of chapters and their key findings

Chapter 1

Chapter 1 presented background information on athletic development, injuries in pre-elite athletes, the sport of netball, the importance of injury prevention, types of injury prevention and models of injury prevention. One model of injury prevention is the six-stage TRIPP framework, which has been promoted as an approach that leads to real-world injury prevention gains. It has provided the foundation for the current investigation into injury prevention in pre-elite athletes. Chapter 1 outlines each of the TRIPP stages and any evidence of these stages being applied in the sport of netball.

Chapter 2

Chapter 2 reports the findings of a prospective study investigating health problems at the 2018 17/U & 19/U Australian National Netball Championships with comparison of two surveillance methodologies. One hundred and ninety-two athletes were observed, and injuries were recorded using medical attention and self-report data collection methods. There were 103 medical attention injuries sustained by 80 athletes, resulting in an incidence rate of 89.4 injuries per 1000 player hours. The most frequently recorded medical attention injury diagnoses across both age groups were lateral ankle ligament sprains (n=14, 13.6%), foot blisters (n=11, 10.7%) and lumbar pain (n=10, 9.7%). Ankle sprains (n=4), anterior cruciate ligament (ACL) ruptures (n=3) and concussion (n=3) were recorded as the highest sports

incapacity injuries. Foot blisters (n=2) and foot sprain (n=2) also accounted for multiple incidences of a sports incapacity injury diagnosis. Of the 103 medical attention injuries, the most frequent 'mechanism of injury' was 'unknown/missing' (n=32, 31%). The second most frequent was collision (n=17, 17%). The self-report data collection revealed that 46 (27.2%) athletes arrived at the tournament with a health problem and there was a significant increase in health problems during the tournament as there were 57 (39.3%) self-reported health problems at the conclusion of the tournament (RR 1.44 95%CI 1.05-1.99, p=0.030). Finally, combining both the medical attention and self-report health problem data collection methods identified more health problems than the use of one method alone.

Chapter 3

Chapter 3 reported the outcome of a systematic review on injury prevention strategies specific to pre-elite athletes competing in Olympic and professional sports. Studies were considered if their included data was specific to pre-elite athletes (determined by the T3/4 levels of the FTEM model), featured an injury prevention intervention, provided sufficient data related to injury so the effect could be analysed, and involved a randomised or non-randomised controlled trial or prospective cohort. Eleven studies satisfied the inclusion criteria, but none of these demonstrated low risk of bias. Four different types of intervention were identified: exercise, psychological, equipment and nutrition. There is limited evidence from level 2 and 3 studies suggesting exercise and psychology interventions may prevent injury in pre-elite athletes. However, the exercise interventions had high risk of bias, low levels of intervention reporting and minimal evidence of implementation planning. There continues to be a need for quality research designs confirming the clinical impact of existing injury prevention interventions for pre-elite athletes.

Chapter 4

A prophylactic ankle taping policy was in place by Netball Australia, requiring all athletes to tape their ankles for training and matches but there was limited recent evidence for this intervention. In Chapter 4, ankle taping was scientifically evaluated under 'ideal conditions' according to TRIPP Stage 4. An Active Movement Extent Discrimination Apparatus (AMEDA) was used to assess proprioception

before and after tape was applied and after a netball session before and after tape was removed. Two different tape conditions were assessed, applied by a Sport and Exercise Physiotherapist and self-applied tape. This study found that proprioception improves immediately after application and is maintained throughout a netball session and that there is no difference between tape conditions.[138] Based on this evidence it appears that the taping procedure increases proprioception and may address the hypothesised risk for ankle injury. Previous basketball research has demonstrated ankle tape prevents injury.[139,140] A barrier to performing research to assess the efficacy of ankle tape to prevent ankle sprain in pre-elite netball athletes is the need for a control group to not wear tape. Pre-elite athletes would not be willing to risk spraining their ankles by not wearing tape. Based on previous research,[139,140] and our recent findings, Netball Australia should continue to encourage its pre-elite netball athletes to tape their ankles.

Chapter 5

TRIPP Stage 5 was applied to improve implementation of Netball Australia's KNEE program. Concept mapping was used to consult the State U/17 & U/19 coaches, strength and conditioning coaches, and physiotherapists as to what they identified as challenges to using the KNEE program. Athlete engagement, supervision/correction of technique, time constraints, athlete technique, education and support staff resourcing were deemed to be the most important challenges to address. Supervision/correction of technique, time constraints, athlete technique, support staff resourcing, and athlete engagement were identified as the most difficult challenges to overcome. This information will help guide future implementation planning.

Chapter 6

Injury surveillance was repeated at the 2019 17/U and 19/U ANNC and a foot blister prevention intervention was implemented. One hundred and ninety-two athletes were observed, and injuries were recorded using medical attention and self-report data collection methods. A foot blister prevention pack and advice sheet were provided to each athlete six weeks prior to the 2019 ANNC. There were 95 medical attention injuries reported across 73 athletes over a six-day period at the 2019 ANNC, at an incidence rate of 82.5 injuries/1000 player competition hours. Ankle sprains (n=16, 16.8%), lumbar

pain (n=12, 12.6%) and foot blisters (n=8, 8.4%) were the most frequently reported injuries. Thirty per cent of athletes started the tournament with a self-reported injury/illness. There were eight reported foot blisters in 2019 compared to 11 in 2018, resulting in an IRR of 1.38 (95% CI: 0.50–3.94, p=0.50). No foot blisters caused sports incapacity in 2019, compared to two cases of sports incapacity foot blisters in 2018.

Ankle sprains (n=14) were also the most frequent injury at the 2018 ANNC,[114] indicating a need for more targeted injury prevention strategies. There were three fewer foot blisters in 2019 compared to 2018, which was not statistically significant. Foot blister discomfort can impact performance as blisters can be distracting and result in biomechanical changes.[141,142] They can be easily prevented with correct footwear and foot hygiene, so this reduction is encouraging but it is not unreasonable to aim for eradication of foot blisters at future netball tournaments.

Discussion of the key thematic findings of the thesis

The implementation of injury prevention strategies in a pre-elite population is challenging

Understanding the context of the injury problem supersedes all other injury prevention requirements.[143,144] Injury prevention in high-performance sport therefore needs to be led by sporting organisations rather than researchers trying to 'translate' their research findings for a sporting organisation with little regard for its context. The benefit of collaborating with researchers early has been recognised in a report released by the Australian Government, outlining that businesses collaborating with research organisations are three times more likely to experience productivity growth.[145] It is also recognised that research is more effective if it is driven by industry; hence, the Australian Government has developed a service to empower businesses to engage with research organisations.[146,147] Injury surveillance is widely conducted in professional youth football academies but use of injury data by coaching staff appears to be poor.[148] Coaching staff engagement is essential to achieve injury prevention in sport.[149,150] If injury prevention was prioritised by sporting organisations we may see improved coach engagement and, therefore, more meaningful research resulting in effective implementation of injury prevention strategies. Perhaps the only way to achieve this, as suggested by

Ekstrand,[151] is to lift the level of importance of health professionals within a sporting organisation hierarchy – for example, to include a health professional on the board. Baugh et al.[152] have demonstrated the impact of organisational structure on injury rates, showing that National Collegiate Athletic Association (NCAA) schools with sports medicine departments financed by and reporting to athletic departments rather than medical institutions had 31% higher injury incidences. If health professionals could be more autonomous within a sporting organisation, perhaps injury prevention strategies would be prioritised and organisationally endorsed, resulting in lower injury rates.

Injury prevention processes such as injury surveillance and implementation methods must be tailored to the pre-elite athlete. We cannot assume that injury prevention strategies found to be effective in the community or at elite levels will also be effective for pre-elite athlete groups. Further, pre-elite athletes, when compared to community-based athletes, are commonly more invested in their development and self-management but at the same time often have more competing demands, such as school and multiple teams/sports demands, than elite athletes.[14,15] Current pre-elite athletes are predominantly 'Generation Z' athletes (i.e., born between 1996 and 2012) with differing values and priorities. Several surveys have found that Generation Z are heavily reliant on technology, self-educated and value treating people with respect, ethical behaviour, fair compensation and transparent communication.[153] Therefore injury prevention strategies need to be communicated well, participants need to be treated fairly and technology must be embraced. Because Generation Z athletes have different characteristics and values to other generations, injury prevention for pre-elite athletes warrants prioritisation by sporting organisations for specific strategies to be developed for this cohort.

Implementation of an injury prevention strategy requires an organisation to move from its present state to a desired future state. This is also known as planned organisational change,[154] for which many change management models exist. Yet these models have not been incorporated into any existing injury prevention frameworks.[155] Stouten et al.,[156] after reviewing the literature, proposed ten change management principles. The first step is to 'get facts regarding the nature of the problem', which could be interpreted as TRIPP Stage 1, and the second step is to 'assess and address the organisation's readiness for change'. A critical part of this step is ensuring senior leadership is ready and capable of

guiding and implementing change. Without the endorsement and guidance of senior leadership, implementation of injury prevention strategies will fail.[157] The third step consists of implementing an evidence-based change intervention and the fourth step focusses on developing effective change leadership throughout the organisation. The fifth step uses multiple communication channels to help change recipients (i.e., athletes and coaches) understand the reason for change and the sixth step recommends working with social networks to tap their influence. The seventh step encourages the use of tools to support implementation such as goal setting and optimising change recipient participation. The eighth step promotes small-scale change interventions to adjust for local requirements (i.e., available resources) and the ninth step assesses change progress over time. The final principle proposed by Stouten et al.[156] is 'institutionalise the change to sustain its effectiveness'. This means integrating the change into the larger systems of the organisation, including its culture and management systems. A key requirement for this to occur is having a committed board that can help make change sustainable by providing critical resources as needed and by recruiting senior management who will ensure the continuity of change.[158] Without incorporating change management principles into injury prevention strategy implementation, we will not see a reduction in injury rates.

Australia's federated structure also poses a challenge for implementing injury prevention strategies for pre-elite athletes.[159] For example, Netball Australia has eight state and territory member organisations. These state and territory member organisations provide support and services for all pre-elite athletes. Therefore, to implement injury prevention strategies for Australian pre-elite netball athletes, change management needs to occur across nine different organisations. This requires not only strong leadership but also excellent communication skills, coordination and commitment by all organisations. The federated structure creates layers of administration and management resulting in duplication of processes and inefficiencies.[160] A sports injury prevention framework, incorporating change management principles, developed in consultation and agreed upon by all member organisations could help address the challenges created by a federated structure.

Prevention frameworks are sequential and do not consider measures in place already. This should be considered when attempting to apply the TRIPP framework in a pre-elite population with established prevention programs in place.

The TRIPP framework focuses on translating research into prevention practice in a sequential manner but it may be necessary to rethink this approach, particularly when working in high-performance sport. Although all steps of the TRIPP framework are essential for injury prevention, it is not always practical and/or feasible to use this sequential format in the high-performance sport setting. This is evident throughout this thesis. The first task when researchers and high-performance sporting organisations collaborate is to understand the context,[143,161] including what injury prevention strategies are currently in place in the sport, how the injury prevention strategies are assessed, how well the strategies are being adopted and the level of evidence supporting their use. With this additional information, researchers and high-performance staff can collaborate in a continual improvement process. The TRIPP steps can be used as a guide for planning meaningful injury prevention projects to improve upon what exists or remove existing ineffective strategies rather than needlessly initiating the TRIPP framework in a sequential manner. Importantly, any researcher attempting to undertake the TRIPP process without first understanding what measures, policy and processes are already in place is unlikely to be effective when working with sporting organisations.

Given the ever-changing nature of high-performance sport, a contingency approach often needs to be adopted where different situations require different methods of management. An example of this is how the TRIPP framework was used to support the collaboration with Netball Australia. Firstly, efficacy trials were not completed, and injury surveillance had not been implemented before introducing the KNEE program to the netball community. This limits Netball Australia's ability to measure effectiveness of the KNEE program, which can then negatively impact ongoing adoption and implementation of the program as well as jeopardising ongoing funding for the program. In response, injury surveillance was conducted[114] (i.e., TRIPP Stages 1 and 2), identifying ankle and knee injuries as the most frequent. Netball Australia's staff, using research evidence and clinical experience, had already developed a prevention program for knee and ankle injuries, so the next logical progression was to apply TRIPP Stage 5 using concept mapping to investigate the challenges to implementing the KNEE

program.[162] The next stage would be to review the KNEE program by revisiting TRIPP Stage 3 to address the challenges to implementation and then reapply TRIPP Stage 5, using Intervention Mapping (Step 5) to plan implementation. Finally, the injury surveillance (TRIPP Stage 6) would be repeated to test effectiveness in a real-world setting. Our investigation demonstrates that the TRIPP framework is useful but not in its intended sequential manner when working in a high-performance environment with existing programs.

An additional challenge for using this framework is that it is time-consuming to complete all six stages, possibly taking considerable time (multiple seasons) to complete. TRIPP Stages 1 and 2 involved a three-month process to prepare for data collection, collect data and analyse data.[114] TRIPP Stage 3 was a two-month process of searching, screening and extracting data from the literature[104] and this was only Step 1 of a six-step intervention development process.[67] TRIPP Stage 4 was a two-month process for planning, executing and analysing the results of a randomised controlled trial.[138] In this stage we sought to understand the mechanism by which ankle tape prevents ankle sprain. Previous studies have shown efficacy of taping/bracing in other populations, but this has not been assessed specifically in pre-elite netball. TRIPP Stage 5 was a two-month process for planning, administering and analysing the concept mapping data to determine the barriers to implementing the KNEE program.[162] This only partly fulfilled Stage 5; using IM (Step 5) to plan implementation would have involved an additional time cost. Finally, TRIPP Stage 6 incorporated an additional three-month process to prepare the intervention, prepare for data collection, collect data and analyse data. In total, completing all of the TRIPP stages was a 12-month process of planning, enacting and analysing in a full-time capacity. In reality, it was an even longer process due to the negotiations required with key stakeholders for when each stage could be conducted and waiting for those opportunities to arise. Currently, within Australian National Sporting Organisations (NSOs), including Netball Australia, there are no dedicated personnel employed in a full-time capacity to oversee and manage the processes outlined above. Further, high-performance sport is known for its high staff turnover[163] and it is therefore difficult to maintain the momentum and direction of injury prevention strategies with lengthy timeframes. Additionally, delays and changes in staff can also result in initial data collection not reflecting current injury profiles. This reinforces the need for

sporting organisation executives to set a culture and legacy of injury prevention. This could be achieved by embedding injury prevention strategies into policy and strategic plans and employing researchers with a multi-disciplinary and clinical focus within high-performance sport for sustained injury prevention success.[164]

TRIPP Stage 1 (Injury surveillance)

Reflections and learnings from applying TRIPP Stage 1 in the field

TRIPP Step 1 requires accurate injury data collection to allow comparison between injury surveillance programmes. This requires consistent injury definition and recording methodology be used.[46] The Orchard Sports Injury Classification System (OSICS)[165] was developed in 1992 and has been consistently updated, with the most recent version (13.5) released in July 2021. It is a commonly used system that has been shown to result in high levels of agreement among data recorders.[166] However, more than a reliable classification system is required for accurate data collection. Wik et al.[167] identified that research-invested clinicians reported 8.8 times greater injury incidence of non-time-loss injuries than their colleagues not involved in research. At the commencement of this thesis, netball had implemented a paper-based medical attention surveillance system, but it was unclear whether these data had been analysed and reported. All clinicians entering the data were primarily engaged to provide physiotherapy services to their state teams and, therefore, were likely not engaged in the surveillance system. Extrapolating from Wik et al., it is likely that injuries were under-reported prior to the study reported in Chapter 2 of this thesis.[114]

Another area for improvement of TRIPP Stage 1 is expanding 'injury surveillance' to 'injury surveillance and its context', as presented by Bolling et al.[143] They argue that because of the complexity of sports injury, context needs to be determined from the outset; otherwise, context-free preventative solutions will be developed. Environmental, sociocultural and individual contextual aspects such as beliefs, attitudes, culture, social structures, governance, policy and budget should be identified when describing the sports injury problem. Verhagen et al.[144] also stress the importance of understanding context when describing Step 1 of their Knowledge Transfer Scheme (KTS). The first KTS step, labelled 'Problem statement', includes not only a description of a health problem but also a description

of the health problem's impact on the community and its specific behavioural and environmental causes. If additional contextual information is sought at the time of injury surveillance, injury prevention initiatives could be more effective.

Most academic sport injury prevention models[43,45,168] assume there are no existing prevention strategies in the target population, but this would be rare in high-performance sport. O'Brien et al.[169] proposed the Team-sport Injury Prevention (TIP) cycle, stating that sport practitioners require a model that is directly applicable to their team's specific context. Their first phase of 'evaluation' includes not only an assessment of current injury prevalence but also injury prevention strategies in situ. This is part of understanding context, as recommended by Bolling et al.[143] and Verhagen et al.[144] This was undertaken during the initial strategising scope of studies with Netball Australia. We learnt that injury surveillance had been attempted at the 2017 17/U and 19/U ANNC, an ankle taping policy was in place and the KNEE program had been implemented.

Netball specific injury surveillance (TRIPP Stage 1)

Injury rates at the 2018 17/U & 19/U ANNC were high, with an incidence rate of 89.4/1000 player hours.[114] We found that across a six-day tournament ankle sprains (n=14), foot blisters (n=11) and lumbar pain (n=10) were the most frequently recorded medical attention injuries.[114] Ankle sprain (n=4), ACL rupture (n=3) and concussion (n=3) were the highest sports incapacity injuries, followed by foot blisters (n=2) and foot sprain (n=2).[114] Ankle sprains and knee injuries have consistently had the highest incidence rate in netball over the past 25 years.[56-58,131] However, of the 46 studies identified in a recent netball injury surveillance systematic review,[54] only three studies[114,115,128] have specifically reported concussion rates and three studies[55,58,114] reported foot blister rates, which does not provide us with an accurate understanding of netball injuries.

Concussion incidence in netball appears to have increased over the past 20 years. In 1998, Finch et al.[115] reported a frequency of just 1.6% (n=4) over two consecutive five-month seasons. In 2014, there was one concussion recorded from 154 netball injuries presenting to an emergency department within a two-year period.[128] Finch et al.[129] reported an 8% annual increase in concussion sustained by netball athletes from 2002–03 to 2010–11. One possible explanation of this increase in concussions is potentially

multifactorial in nature. Historically, concussions have not been recognised and formally diagnosed. Another potential explanation is that there are now more collisions occurring in netball,[130,131] resulting in more concussions.

Foot blisters have not been frequently reported in the netball literature. However, in 1983 Hopper[55] recorded 45 foot blisters across a 14-week season for 3108 netball athletes, translating into 1.4% of athletes sustaining a foot blister. A similar frequency of 2% (n=2) was reported from a three-day netball tournament in 1995.[58] Foot blisters can severely impair function and concentration,[141,142] and future netball injury surveillance initiatives should ensure foot blisters are recorded to obtain an accurate netball injury profile. The type of playing surface, sock, shoe and training load should also be recorded to enhance our aetiological knowledge.

Two injury surveillance methods were implemented and compared at the 2018 17/U & 19/U ANNC. The HPQ identified 26 injuries/illnesses that were not recorded in the Athlete Management System (AMS), 12 of which were overuse injuries and ten illnesses. Conversely, the AMS recorded 33 injuries not identified in HPQ. This demonstrates that using multiple injury surveillance tools results in more accurate data collection. It also confirms the usefulness of the HPQ to capture overuse injuries and illnesses and is not reliant on a health professional to capture data. It is also possible that self-report data can capture injuries when athletes fail to report their injury to a health professional due to pressure from coaches, parents, and peers.[29] The HPQ can be used for injury surveillance in many development athlete settings where surveillance may have been previously considered not possible.

The HPQ also provides us with additional information about extent of symptoms, impact on training/competition and affect on performance.[102] It's important to recognise that athlete responses may not be a true indication of injury, rather a reflection of the athlete's coping skills. It is possible for an athlete to use injury as an excuse for poor performance or as a coping mechanism to manage the stress of high-performance sport.[170,171] To gain an accurate understanding of self-report injury surveillance, perhaps a questionnaire such as the Athletic Coping Skills Inventory[171] can be employed and interpreted by a psychologist.

TRIPP Stage 2 (Establish aetiology and mechanisms of injury)

Reflections and learnings from applying TRIPP Stage 2 in the field

Our findings revealed the importance of recording aetiology and mechanism of injury to help guide future injury prevention interventions. Additional injury/athlete characteristics such as previous injury, sex, age, height, weight, dominant limb, level of competition, tournament or in-season, match or training, time of year, playing position, position on court, time of injury, menstrual cycle information etc. can provide valuable information when developing injury prevention strategies. A challenge for collecting these data is that it is more time consuming for the clinician to record and often the required information is unknown at the time of data entry.[172] Therefore, it is not uncommon to have a high level of missing data or non-descriptive data (i.e., 'other'), as demonstrated in our study[114] and other studies.[55,58] If clinicians – or, better, researcher/clinician partnerships – were more invested in research outcomes, more accurate aetiological and mechanism of injury data might be obtained. Similarly, these results could be enhanced if epidemiology were included in undergraduate and postgraduate clinician education and recording of this information was mandated in policy, job descriptions or funding agreements.

The literature suggests there is an association between hormonal fluctuations during a menstrual cycle and ACL injury.[173] There is also evidence for Relative Energy Deficiency in Sport (RED-S) causing impairment of menstrual function, bone health and immunity.[174] To improve our understanding of these physiological functions, there is a need to continue to collect these data.[175] However, despite the evidence for collecting menstrual cycle information, team physiotherapists did not record this information for over half of the injuries sustained at the 2018 17/U & 19/U ANNC (Chapter 2). This was a missed opportunity to identify and manage athletes who may be experiencing RED-S and to gain a better understanding of the degree of association between hormone levels and ligament injury.

Netball specific mechanisms of injury and aetiology (TRIPP Stage 2)

We found that new injuries occurred nine times more frequently than recurrent injuries.[114] Langeveld et al. also reported new injuries to be more frequent.[57] This finding suggests that either tertiary prevention has been effective for preventing injuries from recurring in this pre-elite population or there

has been previous under-reporting of injuries in this pre-elite population. Regardless, it indicates a need for a greater focus on primary prevention to prevent new injuries from occurring.

Collisions and landings have consistently been the most frequent mechanisms of injury in netball over the past 30 years. The second most frequent mechanism of injury after 'unknown/missing' at the 2018 17/U & 19/U ANNC was 'collision'.[114] Hume and Steele[58] also found collision to be the second most frequent mechanism of injury behind 'other'. This is problematic and improving collection of mechanism of injury data needs to become a priority in future surveillance studies. This can be resolved by data collectors being involved in the research team and by reviewing video footage for accurate injury analysis. Collision was the third-highest mechanism of injury at the 1988 Australian netball championships and 'incorrect landing' was the most frequent,[59] whereas 'contested landing' was the fifth most frequent mechanism of injury at the 2018 17/U & 19/U ANNC[114] and fourth most frequent mechanism of injury at the 1995 New South Wales State Netball Championships.[58] 'Incorrect landing' was less frequent than 'collision' in 2018 compared to 1988, suggesting coaching of landing technique may have improved over the past 30 years and perhaps that more attention should be given to reducing the number of collisions.

TRIPP Stage 3 (Develop preventive measures)

Reflections and learnings from applying TRIPP Stage 3 in the field

Developing an injury prevention strategy relies on a combination of scientific evidence, practitioner expertise and end-user values. Donaldson et al.[67] proposed the six-step IDP to fulfil the requirements of Stage 3 of the TRIPP[43] and van Mechelen's 'sequence of prevention' model.[42] There is limited evidence of organisations applying this process for injury prevention development.[67,176] It was first applied within community Australian football to develop FootyFirst, a lower-limb injury prevention exercise training program.[67] Subsequently the IDP has been used to plan for intervention development in youth handball but has not yet been implemented.[176] We completed Step 1 of the six-step process (i.e., use the research evidence and clinical experience) by undertaking a systematic review[104] but could not complete the six-step process due to time constraints. The IDP is a systematic and pragmatic guide but requires a significant time commitment, as demonstrated by the 14 months required to develop FootyFirst.[67] The

'Intervene' stage of the TIP cycle[169] is less time-consuming as it consists of three steps, as follows: obtain administrative support,[177] engage key partners to design a strategy[178] and, finally, plan for implementation in a timely manner.[169] Perhaps the 'Intervene' process is a more realistic and practical fit than the IDP for developing an effective and timely intervention in high-performance sport.

Netball specific development of preventive measure (TRIPP Stage 3)

Several netball-specific exercise injury prevention interventions have been developed, such as 'Down to Earth',[179] the KNEE program,[180] 'Knees up'[58] and 'Netball Smart'.[181] The 'Knees up' program, developed in 1995 by Sports Medicine Australia, provides advice on netball injury prevention and management.[58] The 'Netball Smart' program was developed in 2004 by New Zealand's Accident Compensation Corporation (ACC) and Netball New Zealand based on 'SportSmart', a 10-point action plan for sports injury prevention developed by the ACC.[182] The 'Down to Earth' program was developed in 2006 by researchers at the School of Human Movement and Sport Sciences, University of Ballarat.[179] It was based on the best available research at the time, specifically adapted for netball from sports such as basketball, soccer and European handball. The KNEE program was developed in 2015 by Netball Australia using the principles of existing injury prevention programs.[180] There is no published evidence describing how these programs were developed but we must acknowledge that implementation science was still in its infancy within sports injury prevention when these programs were developed.

Step 1 of the IDP process undertaken in this thesis was completed by conducting a systematic review[104] of injury prevention strategies specifically trialled with pre-elite athletes. Limited evidence from level 2 and 3 studies was identified, suggesting exercise[183-189] and psychological[190,191] interventions may assist in preventing injury within the pre-elite athlete cohort. It is noteworthy that netball did not feature in any of the included studies. The other types of interventions included in the systematic review were equipment[192] and nutrition[193] strategies. All published netball injury prevention strategies to date have focused on exercise interventions, but these have not been trialled in the pre-elite population. There would be value in assessing these interventions in subsequent pre-elite populations in addition to considering other types of intervention, such as psychological support or policy change as demonstrated within 13–14-year-old ice hockey leagues,[194] New Zealand Rugby[136] and baseball.[195]

TRIPP Stage 4 ('Ideal conditions'/scientific evaluation)

Reflections and learnings from applying TRIPP Stage 4 in the field

Randomised controlled trials are the foundation of evidence-based practice.[196] Unfortunately, there are very few randomised controlled trials inclusive of high-performance athletes.[197] It is often difficult to access elite sporting populations[164] as the experimental-control requirements will often interfere with typical training and competitive preparations and the chance of not receiving the experimental intervention is at odds with the high-performance mind set of 'searching for the winning edge'.[197] Additionally, it is critical that researchers take into consideration the current safety/injury culture of the sport,[43,198] which means athletes, coaches and support staff are not unduly concerned about athlete safety and welfare if participating in research. Most high-performance sports already have injury prevention strategies in place. Therefore, perhaps TRIPP Stage 4 needs to focus on developing evidence for a strategy, not just on proving efficacy because it is unethical to remove a prevention strategy that has already been implemented. Another consideration is the sample size in high-performance sport because of the small number of high-performance athletes when compared to the community. Nevertheless, despite the difficulty in obtaining significant results leading to generalisable inference, research in high-performance sport can result in improved decision making for the sport. Recommendations have been made for statistical techniques which can improve insights from suboptimal sample sizes.[199] Perhaps in high-performance sport, injury prevention strategies need to be developed based on context and existing evidence.[144] It may be more realistic to evaluate effectiveness of injury prevention strategies in the real-world using a cohort study rather than attempting to assess efficacy in a more controlled environment which requires the need of a control group.

Research utilising approaches other than randomised controlled trials, such as a recent observational study[200] and nonrandomised intervention study,[201] has demonstrated how partnerships between researchers and high-performance sport can be mutually beneficial, supporting both high-performance outcomes and improved professional practice.[164] Research in high-performance sport must remain relevant for those at the 'coal-face'[202] and must maintain rigour to ensure studies are not poorly interpreted or misleading.[203] To conduct sound scientific evaluation, it is important to monitor potential

athlete recruitment bias, the compliance and fidelity of the intervention, drop-out rates and adverse effects of the intervention. Establishing efficacy of an injury prevention strategy remains critical for the injury prevention implementation process.[43]

Netball specific scientific evaluation of injury prevention strategies (TRIPP Stage 4)

We found proprioception improves and is maintained during a netball session with either SEP or self-applied taping.[138] There have been limited scientific evaluations of injury prevention strategies in the sport of netball. Two biomechanical studies have examined the effect of an ankle brace or tape on lower limb electromyographic, kinematic and kinetic variables during a netball-specific landing task.[204,205] Another study reported an improvement in lower-limb biomechanics when 11–13-year-old netballers underwent neuromuscular training.[206] Additional research studies have been conducted within netball to investigate the effect of specific training on performance but not on injury prevention.[207-209] Given netball's injury profile has not changed over the past 20 years,[58,114] it is a concern that limited research has been conducted to support the efficacy of enduring netball-specific injury prevention strategies.

TRIPP Stage 5 (Describe intervention context to inform implementation strategies)

Reflections and learnings from applying TRIPP Stage 5 in the field

Implementation science is an emerging area within sports medicine. Applying implementation science within sports injury prevention was first described in 2006.[43] It is widely accepted that it takes an estimated average of 17 years for research evidence to reach clinical practice;[210-212] perhaps the same will hold true for implementation science to become more mainstream within injury prevention initiatives. The body of knowledge in sports medicine implementation is growing[76,79,83,84,213] but utilising implementation science would not yet be regarded as common practice,[76,98] even though international sporting federations highly value this type of research.[97] Several tools can be utilised to help fulfill TRIPP Stage 5, such as RE-AIM SSM (Sports Setting Matrix),[76] concept mapping,[88,213] intervention mapping Step 5[79] and the knowledge and attitudes questionnaire.[91] These tools can be used to either help plan implementation or evaluate implementation of already established injury prevention strategies. The challenge is to select the most appropriate tool for the setting in which the strategy has been applied.

Coach education has been recognised as an effective implementation strategy for achieving high compliance rates for injury prevention initiatives. In a South African rugby study, it was demonstrated that coach education was critical for improving athlete injury prevention behaviours.[214] In netball and soccer, coach education has also been shown to change the way coaches coach and a vehicle for indirectly educating athletes.[85,92] The principles of injury prevention need be included in all coaching accreditation courses for implementation of injury prevention strategies to be successful.

All socioecological levels of an organisation need to be involved and committed to implementation planning for an injury prevention strategy to be effective.[76,215] Coaching staff alone cannot deliver a successful program, as they rely on the athletes to attend training, execute the program with fidelity and integrate the program into their other training sessions. The coach needs to be supported by managers and the executive above them to ensure they receive the necessary training and education as well as resources and support materials that are regularly reviewed and updated. Often national and State Sporting Organisation (SSO) executive endorsement is critical for adoption, implementation and maintenance of an injury prevention strategy.[76,213] For greater implementation success, TRIPP Stage 5 should emphasise the importance of involving all socioecological levels of operation within sport.

Netball specific implementation planning (TRIPP Stage 5)

Concept mapping was used to help improve the implementation of the KNEE program.[162] Netball Australia implemented the KNEE program in 2015 but high lower-limb injury rates were still a feature of the 2018 17/U & 19/U ANNC.[114] Using concept mapping, the following challenges were determined to be the most important and difficult to overcome when implementing the KNEE program in pre-elite netball: 'athlete engagement', 'supervision and correction of technique', 'time constraints', athlete technique', 'education' and 'support staff resourcing'. With this new knowledge, intervention mapping Step 5 can now be used to improve implementation by effectively attending to each of these recognised barriers.

Five netball injury prevention implementation studies have been identified within the literature.[85,92-95] Areas for improvement include program modifications,[85] coach education,[85,92] emphasis placed on injury prevention benefits to achieve attitudinal change, and the involvement of significant others and

role models to promote injury prevention programs.[93] Additionally, coach and player attitudes to injury need further investigation, as a high prevalence of players playing-on despite being injured was identified.[95] These studies provide valuable insight for improving implementation of current netball injury prevention strategies and inform future implementation planning.

TRIPP Stage 6 (Evaluate effectiveness of preventive measures to implementation context)

Reflections and learnings from applying TRIPP Stage 6 in the field

This stage involves implementing an intervention in a real-world context and evaluating its effectiveness. While ankle sprains and ACL ruptures are recognised as the most frequent sports incapacity injuries within pre-elite netball athletes,[114] a joint decision with Netball Australia was made to implement a foot blister prevention strategy at the 2019 17/U & 19/U ANNC. This decision was due in part to Netball Australia's KNEE program being already implemented to reduce lower limb injuries.[180] Barriers to implementation of the KNEE program were identified in Chapter 5;[162] however, there was insufficient time to address these barriers and then assess the effectiveness of the KNEE program at the 2019 17/U & 19/U ANNC. Instead, a proven foot blister prevention strategy was implemented as blisters can be easily prevented with correct footwear and foot hygiene.[120,121]

We repeated the 2018 17/U & 19/U ANNC medical attention and self-report injury surveillance in 2019 (Chapter 6). Netball Australia initiated injury surveillance at the 2017 17/U & 19/U ANNC, asking team physiotherapists to complete paper forms for every injury their athletes sustained. Team physiotherapists were required to complete this task in addition to maintaining their own injury records. In 2018, injury surveillance was advanced by introducing electronic injury records for the team physiotherapists to reduce their workload and simplify analysis.[114] Additionally, athlete self-report injury/illness data were collected to compare injury surveillance methods and potentially improve accuracy of data collection.[114] In 2019, team physiotherapists and athletes were provided with 2018 results and were asked to repeat the same injury surveillance. The athlete response rate improved to above 70% across all four health problem questionnaires in 2019, compared to 2018 when the response rate was below 50% for the two post-tournament health problem questionnaires. There were also fewer missing data for medical attention injuries; for example, in 2018, 32 (31%) injury records did not

include mechanism of injury data, which decreased to 10 (11%) incomplete injury records in 2019. This improved HPQ response rate and medical attention data collection was possibly due to athletes and physiotherapists being more familiar with the AMS in 2019 and results from 2018 had been shared which possibly provided more context. Also, coaches and high performance managers actively endorsed the research in 2019 compared to 2018. Establishing quality injury surveillance takes time and commitment by all when working within high-performance sport, where surveillance is an ongoing process enduring beyond any research project timeframes. Injury surveillance needs to be a continuous, evolving process, rather than just the first and last step of the TRIPP framework. It is advocated that prevention frameworks should be updated to reflect this ongoing need for the organisations involved.

Netball specific evaluation of effectiveness of injury prevention strategy

One previous netball study has examined the effectiveness of an injury prevention strategy in the 'real world'.[99] Elphinston and Hardman[99] provide a realistic view of implementing an injury prevention strategy for an international netball team. Using a multidisciplinary team (i.e., coach, physiologist, physiotherapist and a strength and conditioning coach), multiple injury prevention strategies were implemented including: 1) multidisciplinary athlete profiling, 2) athlete performance self-assessments, 3) functional stability program, 4) strength and conditioning programs, 5) individual prophylactic programs, 6) regular multidisciplinary meetings and 7) a Head Physiotherapist being appointed to the program. Injury incidence rates and statistical analysis were not reported, making it difficult to ascertain the relative effectiveness of this approach. Nevertheless, this case study provided a realistic example of the high-performance sport environment in an operational and multidisciplinary sense, illustrating the need for researchers to adapt their approach in order to contribute to injury prevention.

Foot blisters are a common occurrence in netball but there is no evidence of foot blister prevention strategy implementation within the netball population. Of the many netball injury surveillance studies,[54] only two have reported foot blister injury rates, once in 1986[55] and then again in 2000.[58] In 2018, foot blisters continued to be problematic at the 17/U & 19/U ANNC, causing player discomfort and resulting in sports incapacity for two athletes.[114] We found implementation of a foot blister pack and advice sheet reduced the number of sports incapacity foot blisters from two in 2018 to zero in 2019 and all foot

blisters from eleven at the 2018 17/U & 19/U ANNC to eight at the 2019 17/U & 19/U ANNC, but this was not statistically significant. This strategy could be improved by involving the team physiotherapists in the research project earlier to increase their engagement and highlight the important role they play in educating athletes about foot blister prevention. Given foot blisters have been an issue for netball athletes for over 35 years and can lead to sports incapacity, and should be easily prevented, it is recommended that foot blister prevention continue to be prioritised.

Thesis strengths

This thesis has applied all stages of the TRIPP framework within a sport, which has not been previously demonstrated within the relevant literature. A feature and strength of this body of work is its significant breadth of mixed methodological approaches, including observational studies, a systematic review, randomised controlled trial, concept mapping and an interventional cohort study.

In both observational cohort studies[114] (and Chapter 6) we applied the STROBE statement[72] to ensure high-quality reporting. The OSICS[126] was used for coding injury diagnosis and the IDCF[124] guided our definitions of clinical examination and sports incapacity injuries. A valid and reliable questionnaire, the Oslo Sports Trauma Research Centre (OSTRC) Health Problems Questionnaire (HPQ),[20] was also utilised to collect athlete self-report data. Adopting these measures has resulted in two valid and effective injury surveillance studies of pre-elite netball athletes. While published after the studies were completed, our overall approach and methods align to the recommendations within the IOC's statement on methods for recording and reporting epidemiological data on injury and illness in sport.[47]

The systematic review[104] protocol was registered on the International Prospective Register of Systematic Reviews (PROSPERO) (http://www.crd.york.ac.uk/PROSPERO) and the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) guidelines[216] were followed. Covidence systematic review software (http://www.covidence.org) was employed to ensure accurate article screening and data extraction. The FTEM framework[5] was used to classify athlete developmental level and the Oxford Centre of Evidence-based Medicine (OCEBM) Levels of Evidence[217] was used to determine the hierarchical levels of evidence. To establish transparency of evidence, risk of bias was

assessed using Cochrane Collaboration's tool for assessing the risk of bias in randomised trials.[105] These provisions resulted in a high-quality systematic review identifying level 2 and 3 studies suggesting exercise and psychology interventions may prevent injury in pre-elite athletes.

We produced level 1 evidence by conducting a randomised controlled trial,[138] demonstrating proprioception improves and is maintained during a netball session with either SEP or self-applied ankle tape. We used the AMEDA, which has been shown to be a valid[218,219] and reliable instrument, to test proprioception.[220] To mitigate a learning effect which has been previously reported,[220,221] we randomised the order of tape condition. Double-blinding of our participants would reduce risk of bias; however, because of the nature of the applied intervention (participants clearly knew if they were strapped and who strapped them) we were unable to employ this strategy. Advanced statistical analysis was utilised, such as a mixed effects generalised linear model to test the effect of the taping condition on proprioception over time and a three-way interaction model to assess learning effect. Employing these strategies minimised risk of bias, resulting in a trustworthy study design.

We used concept mapping, which is a real-world pragmatic consultative method to understand the barriers to implementing Netball Australia's KNEE program by creating and organising the ideas of our netball coaches, physiotherapists, and strength and conditioning coaches.[162] Analysis of 69 concept mapping studies revealed strong internal representational validity and very strong sorting and rating reliability for this type of research.[222] We also succeeded in recruiting and retaining a high percentage of invited participants, with 39 of 47 (83%) contributing CM data, thus providing good representation of pre-elite netball coaching and support staff.

Another strength of this body of work is that it focused on the pre-elite population, whose vulnerability to injury, due to a range of risk factors is well recognised. To ensure efficacy and effectiveness, injury prevention strategies must be specific to their target population. Because the pre-elite stage of an athlete's development is critical to their overall athletic development and a critical precedent to future high-performance, we targeted this population.

Finally, we demonstrated how effective organisational collaboration and linkage (i.e., University of Canberra, Australian Institute of Sport and Netball Australia) is conducive to meaningful and impactful research with mutual and system level benefit. The Australian Institute of Sport and University of Canberra recognised the need to develop knowledge around injury/illness prevention in pre-elite athletes and Netball Australia prioritised injury/illness prevention for their pre-elite athletes. This collaboration was effective because the research organisations were guided by Netball Australia's research needs.

Thesis limitations

We attempted to apply the entire TRIPP framework with Netball Australia's pre-elite athletes who had already adopted some injury prevention strategies. This resulted in a wide range of studies but a reduction in depth. Additionally, the timing of the 17/U & 19/U ANNC and national camps also dictated what could be accomplished within those time constraints. And as previously discussed, the concept mapping project could have been improved by the inclusion of athletes. Further, our understanding of the foot blister intervention would have been enhanced by collecting fidelity data. Also, adding an additional AMEDA training session prior to data collection may have reduced the initial learning effect.

We did not follow a specific implementation framework when implementing our foot blister prevention strategy at the 2019 17/U & 19/U ANNC. However, the strategy itself was a proven intervention that has been utilised for many years within the Australian Institute of Sport's Medical Department. Pragmatically, we did not undertake formal implementation planning due to time constraints prior to the commencement of the 2019 17/U & 19/U ANNC. This is not optimal for effective implementation of an injury prevention strategy; however, based on clinical experience and evidence we proceeded with the intervention to determine the effectiveness of an existing tool as a separate question to the development and implementation of a tool. If a framework such as REAIM was used, team physiotherapists, athletes and coaches would have been engaged earlier and invested in the strategy, possibly leading to greater compliance.

Directions for further research

Through the course of this research, we have established annual injury surveillance tools and processes at the 17/U & 19/U ANNC. Further research opportunities include ongoing injury surveillance at these championships, where injury surveillance can be further developed and refined.

Barriers to implementation of the KNEE program have been identified by coaches and support staff within this body of work. Further research is required to tap into and understand the perspectives of the athlete in implementing this program and identify potential barriers to compliance and effective implementation. It is recommended that IM (Step 5) then be applied to address these barriers and inform and support effective implementation planning.

There were three concussions reported at the 2018 17/U & 19/U ANNC and five concussions at the 2019 17/U & 19/U ANNC. We have not addressed this issue within this thesis but preventing concussion should be prioritised in future research endeavours as it is an injury that results in sports incapacity and may contribute to long-term sequelae. Historically these injuries have not routinely been included in netball injury surveillance studies. Future surveillance studies and systems should include concussion within their data capture.

Lumbar pain was the second most frequent medical attention injury at the 2018 (n=10) and 2019 (n=12) 17/U & 19/U ANNC. There is no evidence for a specific prevention strategy for lumbar pain in pre-elite netball athletes, however a functional stability program for an international netball squad has been shown to reduce the incidence of lumbar pain.[99] With Lumbar pain being such a frequent injury in this population, a prevention strategy should be developed and implemented.

One study has previously reported the effect of research-invested clinicians on quality of injury data collection. This can potentially have a significant impact on research outcomes and therefore warrants further research into potential factors that influence clinician data collection behaviours, such as education, experience and the job descriptions within the sports medicine support roles.

Injury has been found to be a major contributing factor to pre-elite athlete dropout.[3] Further research should be implemented with a focus on this vulnerable population to further ascertain the extent of this

issue. This should be of primary importance for sporting organisations at all levels to better support sustainable pathways to high performance into the future.

Conclusion

The aim of this thesis was to develop a holistic strategy to reduce the burden of injuries in pre-elite athletes, using netball as an exemplar sport. To achieve this, we applied the TRIPP framework to a pre-elite netball athlete population using a mixed-methods approach employing established approaches and protocols.

This thesis reconfirmed that ankle sprains are the most frequent injury and ACL ruptures the most severe injury sustained by pre-elite netball athletes. A novel finding was that concussions are a relatively frequent sports incapacity injury in this sport. Our findings support the ongoing need for injury surveillance and the need for injury prevention strategies for pre-elite netball athletes to continue to focus on the most frequent and incapacitating injuries: ankle sprain, lumbar pain, ACL rupture, concussion, and foot blisters.

The practical application of this body of work revealed the importance of researchers working with sporting organisations that oversee talent pathways (i.e., State Sporting Organisations and their partner National Sporting Organisations). Without the collaboration between the Australian Institute of Sport, University of Canberra, Netball Australia and its State member organisations, this research would not have been possible. A flexible contingency approach towards injury prevention assists organisations to improve existing practices rather than following a sports injury prevention framework like a recipe. Although the TRIPP framework is intended to be followed in a sequential order, a learning from this thesis is that it cannot be applied in such a manner without significant challenges to relationships. For example, Netball Australia had already invested a lot of time and resources into developing and implementing the KNEE program. Instead of developing a new program, we worked with Netball Australia to learn how implementation of the KNEE program could be improved. While all steps of the TRIPP framework are essential for injury prevention, the outcomes of this thesis, beyond its individual studies, indicate they should be used as a guide to continual improvement of what the sport has already

implemented. In doing so, researchers embedded within sport can add value to the organisation processes, reducing the need for translation of findings at the end of the process.

Injury prevention processes such as injury surveillance and implementation methods must be tailored to the pre-elite athlete. These processes must be cognisant of the resources available to the organisation. Coaches, physiotherapists, and strength and conditioning coaches are pivotal for injury prevention success, but at the pre-elite level they are not available to the same extent as at the elite level due to resourcing constraints. Sporting organisations wishing to improve injury rates should be aware of the practical barriers to implementing any systems or programs. For this to occur, injury prevention must be prioritised by sporting organisations and be reflected within related policy, strategy, organisational structure and resourcing.

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Appendices

Appendix 1: Human Ethics Committee approval for Chapter 2

Australian Government
Australian Sports Commission

TO: Ms Erin Smyth CC: Dr Mick Drew

FROM: Ms Helene Rushby

SUBJECT: Approval from AIS Ethics Committee DATE: 16th April 2018

On the 10th April 2018, the AIS Ethics Committee gave consideration to your submission titled ***"Injury profile of 17/U and 19/U netball athletes during and after National Championships"*** The Committee saw no ethical reason why your project should not proceed.

The approval number for this project is: 20180404

It is a requirement of the AIS Ethics Committee that the Principal Researcher (you) advise all researchers involved in the study of Ethics Committee approval and any conditions of that approval. You are also required to advise the Ethics Committee immediately (via the Secretary) of:

Any proposed changes to the research design,
Any adverse events that may occur,

Researchers are required to submit **annual status reports** and **final reports** to the secretary of the AIS Ethics Committee. Details of status report requirements are contained in the "Guidelines" for ethics submissions.

Please note the approval for this submission expires on the 31st December 2020 after which time an extension will need to be sought.

If you have any questions regarding this matter, please don't hesitate to contact me on (02) 6214 1577.

Sincerely

Helene Rushby
Secretary
AIS Ethics Committee

AIS

Appendix 2: Information to Participants for Chapter 2

INFORMATION TO PARTICIPANTS

Research Title: Injury profile of 17/U and 19/U netball athletes during and after National Championships

Principal Researcher:

Erin Smyth (0420512039, erin.smyth@ausport.gov.au)
We would like to invite you to participate in this research project. Choosing not to take part will not disadvantage you in any way. Before you decide whether you want to take part, it is important for you to understand why the research is being done and what your participation will involve. Please take time to read the following information carefully and discuss it with others if you wish. Ask us if there is anything that is not clear or if you would like more information.

Aim:

The aim of this research project is to investigate injury and illness incidence in 17/U and 19/U Netball athletes during and one month following the 2018 National Championships.

Benefits:

This study will provide valuable insights into the injury profile of 17/U and 19/U pre-elite Netball athletes to help guide future injury prevention initiatives.

What is involved?

The study will be conducted over a 5 week period (16 April 2018 – 19 May 2018) and will consist of the following:

Online survey

A survey will be accessible through the Athlete Management System (AMS) and consists of four questions that ask whether you have experienced any health problems in the last week. You are asked to provide the most accurate responses that you can.

AMS data entry

Your injury records and netball participation will be recorded on AMS by your team Physiotherapist and Netball Australia selectors. This data will be de-identified to protect your privacy.

Who are we recruiting?

We are recruiting all netball athletes participating in the 2018 17/U and 19/U National Championships.

Adverse effects and withdrawal:

We do not anticipate any adverse effects and you may withdraw at any time without penalty.

Confidentiality:

The confidentiality of your data will be respected at all times. Only researchers directly involved in this project will see your AMS data which will be kept for minimum of 5 years. Data is stored electronically in the AMS and any hard copies will be stored in a locked filing cabinet. Participants' names will not be associated with any aspect of this study; this will ensure anonymity during research and publication. Data will be collated so that an individual's information will not be able to be identified. The AMS data utilised in this study may also be used in future studies. This research will be used to inform the design of injury and illness prevention programs for netball athletes in the future. Results will be disseminated in the form of publications and be included in Erin Smyth's PhD thesis. Follow up support will be provided by the student researcher Erin Smyth between Monday-Thursday, between the hours of 9am and 5pm.

Ethics approval:

This study has been approved by the Australian Institute of Sport Ethics Committee (Approval Number: 20180404). If you, the participant, have any concerns you can contact the secretary of the AIS Ethics Committee on 02 6214 1577.

Further information:

If you have any questions, or you would like further information regarding the project titled**:** *Injury profile of 17/U and 19/U netball athletes during and after National Championships*, please contact the Principal Researcher, **Erin Smyth** of the **Australian Institute of Sport** and **University of Canberra:**
PH: +61 420512039
EMAIL: erin.smyth@ausport.gov.au

Appendix 3: Information for Parent/Guardian of Minor for Chapter 2

INFORMATION FOR PARENT/GUARDIAN OF MINOR (UNDER 18 YEARS) PARTICIPANTS

Research Title: Injury profile of 17/U and 19/U netball athletes during and after National Championships

Principal Researcher:

Erin Smyth (0420512039, erin.smyth@ausport.gov.au)

We would like to invite your child to participate in this research project. Choosing not to take part will not disadvantage your child in any way. Before you decide whether you want your child to take part, it is important for you to understand why the research is being done and what their participation will involve. Please take time to read the following information carefully and discuss it with others if you wish. Ask us if there is anything that is not clear or if you would like more information.

Aim:

The aim of this research project is to investigate injury and illness incidence in 17/U and 19/U Netball athletes during and one month following the 2018 National Championships.

Benefits:

This study will provide valuable insights into the injury profile of 17/U and 19/U pre-elite Netball athletes to help guide future injury prevention initiatives.

What is involved?

The study will be conducted over a 5 week period (16 April 2018 – 19 May 2018) and will consist of the following:

Online survey

A survey will be accessible through the Athlete Management System (AMS) and consists of four questions that ask whether your child has experienced any health problems in the last week. Your child will be asked to provide the most accurate responses that they can. They will be asked to complete the questionnaire four times: 16/4/18, 22/4/18, 29/4/18 and 20/5/18.

AMS data entry

Your child's injury records and netball participation will be recorded on AMS by their team Physiotherapist and Netball Australia selectors. This data will be de-identified to protect their privacy.

Who are we recruiting?

We are recruiting all netball athletes participating in the 2018 17/U and 19/U National Championships.

Adverse effects and withdrawal:

We do not anticipate any adverse effects and your child may withdraw at any time without penalty.

Confidentiality:

The confidentiality of your child's data will be respected at all times. Only researchers directly involved in this project will see their AMS data which will be kept for minimum of 5 years. Data is stored electronically in the AMS and any hard copies will be stored in a locked filing cabinet. Participants' names will not be associated with any aspect of this study; this will ensure anonymity during research and publication. Data will be collated so that an individual's information will not be able to be identified. The AMS data utilised in this study may also be used in future studies. This research will be used to inform the design of injury and illness prevention programs for netball athletes in the future. Results will be disseminated in the form of publications and be included in Erin Smyth's PhD thesis. Follow up support will be provided by the student researcher Erin Smyth between Monday-Thursday, between the hours of 9am and 5pm.

Consent:

Your child will be asked to complete a questionnaire on their smartphone. Prior to this they will be asked to provide your consent, name and contact email. Can you please communicate with your child prior to 16th April 2018 whether you give your consent for them to participate in this research project.

Ethics approval:

This study has been approved by the Australian Institute of Sport Ethics Committee (Approval Number: 20180404). If you, the participant, have any concerns you can contact the secretary of the AIS Ethics Committee on 02 6214 1577.

Further information:

If you have any questions, or you would like further information regarding the project titled**:** *Injury profile of 17/U and 19/U netball athletes during and after National Championships*, please contact the Principal Researcher, **Erin Smyth** of the **Australian Institute of Sport** and **University of Canberra:**

PH: +61 420512039

EMAIL: erin.smyth@ausport.gov.au

Appendix 4: Informed Consent Form for Chapter 2

Injury profile of 17/U and 19/U netball athletes during and after 2018 National Championships

Principal Investigators: Ms Erin Smyth (PhD Scholar, AIS/UC), Dr Michael Drew (AIS), Prof Gordon Waddington (AIS/UC), Dr Juanita Weissensteiner (AIS), Dr Philip Newman (UC), Dr Laura Juliff (Netball Australia), Ms Alanna Antcliff (Netball Australia)

You are invited to take part in this research project.

Please read the **Participant Information Form** carefully as this will tell you about the research project and explain what is involved. This will help you decide if you want to continue and take part.

Ask questions about anything that you don't understand or want to know more about. Before deciding whether or not to take part, you might want to talk about it with a relative, friend or healthcare worker.

Participation

- Participation in this study is entirely voluntary.
- You're not obliged to participate and if you do, you can withdraw at any time without penalty or prejudice.
- To participate, we would like you to complete the online questionnaire: 'Questionnaire on Health Problems'.
- Your participation, personal details and results will be strictly confidential and only the Principal Investigators above will have access to the information.

By ticking the 'I ACCEPT' or 'My Parent or Guardian ACCEPTS' option below you are telling us that you or your Parent or Guardian:

- Understand what you have read.
- Consent to take part in the research project.
- Consent to participate in the research processes that are described.
- Consent to use your personal and health information as described.
- Understand that you are free to not answer specific items or questions.
- Understand that any data or answers to questions will remain confidential with regard to your identity.
- Certify to the best of your knowledge and belief, you have no physical or mental illness that would increase the risk of participating in this project.
- Are participating in this project of your own free will and have not been coerced in any way to participate

☐ I ACCEPT (If you do not accept, please exit the browser)

Minors (Please complete if under 18 years)

☐ My Parent or Guardian ACCEPTS (If they do not accept, please exit the browser)

Parent/Guardian full name: _____

Parent/Guardian email address: _____

Appendix 5: Human Ethics Committee approval for Chapter 4

Dear Erin

The Human Research Ethics Committee has considered your application to conduct research with human subjects for the project "20181527 - Does ankle tape improve proprioception acuity immediately after application and following netball training?".

The Committee made the following evaluation: **Approved**

The approval is valid until: 05/10/2018

The following general conditions apply to your approval. These requirements are determined by University policy and the ***National Statement on Ethical Conduct in Human Research*** (National Health and Medical Research Council, 2007).

Monitoring

You must assist the Committee to monitor the conduct of approved research by completing project review forms, and in the case of extended research, at least annually during the approval period.

Reporting Adverse Events

You must report any unexpected adverse events or complications that occur anytime during the conduct of the research study or during the follow up period after the research. Please refer these matters promptly to the HREC. Failure to do so may result in the withdrawal of the Ethics approval.

Discontinuation of Research

You must inform the Committee, giving reasons, if the research is not conducted or is discontinued before the expected date of completion.

Extension of Approval

If your project will not be complete by the expiry date stated above, you must apply for extension of approval. This must be done before current approval expires.

Retention and Storage of Data

University policy states that all research data must be stored securely, on University premises, for a minimum of five years. You must ensure that all records are transferred to the University when the project is complete.

Contact Details and Notification of Changes

All email contact should use the UC email address. You should advise the Committee of any change of address during or soon after the approval period including, if appropriate, email address(es).

Please do not hesitate to contact us via email humanethicscommittee@canberra.edu.au if you require any further information.

All the best,

Hendryk Flaegel
Research Ethics & Integrity
Research Services
University of Canberra
29/10/2018

Appendix 6: Information to Participants for Chapter 4

PARTICIPANT INFORMATION SHEET

Research Title: Does ankle tape improve proprioception acuity immediately after application and following netball training?

Principal Researcher:
Erin Smyth (0420512039, u3098942@uni.canberra.edu.au)

We would like to invite you to participate in this research project. Choosing not to take part will not disadvantage you in any way. Before you decide whether you want to take part, it is important for you to understand why the research is being done and what your participation will involve. Please take time to read the following information carefully and discuss it with others if you wish. Ask us if there is anything that is not clear or if you would like more information.

Aim:
The aim of this research project is to investigate whether ankle tape improves proprioception (position and movement sense) of the ankle.

Benefits:
The benefit will be the creation of current evidence to support or refute the common practice of taping/bracing to prevent ankle injuries.

What is involved?

1. You will undertake movement sensitivity (proprioception) testing at the ankle in a standing position using an AMEDA device. The AMEDA device consists of a footplate on a platform that can tilt to 5 possible positions resulting in ankle inversion movements between 10.5 and 14.5 degrees from the horizontal. You will be familiarised with the 5 positions in an introductory sequence where the different positions are set in order from smallest (position 1) to largest (position 5). This sequence is repeated 3 times. Following familiarization, the footplate, from its horizontal start position, will be moved to one of the 5 positions which you will then be asked to identify. This will be repeated over 50 trials, each time returning to the start position, with each position presented 10 times in random order. The test is semi-automated and takes approximately 6 minutes to complete.
2. Then depending on which group you've been assigned to, you will then have your ankles taped by a Sport and Exercise Physiotherapist or you will self-tape if that is your normal practice.
3. Proprioception will then be tested again, repeating the 50 trials
4. A Catapult local monitoring system tracker will then be fitted and you will participate in a normal training session or match.
5. Immediately after the training session you will repeat the 50 trials regardless of whether you tape, brace or neither.
6. The tape will then be removed and you will repeat the 50 trials again.

Who are we recruiting?
Pre-elite netball players (17/U & 19/U state representatives and higher)

Withdrawal:
You may withdraw at any time without penalty.

Risks:
The risks to you associated with participation in this study are minimal and are consistent with normal activities undertaken in everyday life in a clinical setting. For example, tripping on a carpet edge. To minimise risk we will brief you on standard procedures for conduct and safety within the research laboratory space.

Confidentiality:
Your results will be kept as confidential as is possible by law. All data will be kept in the possession of the investigators. If the results of the study are published in a scientific journal, your identity will not be revealed. If you wish to withdraw from the study prior to publication of results your data will be removed from the study data. Participants will not be referred to by name during research reports or study discussions. All hard copy records will be stored in a locked filing cabinet in a private office. All computer records are restricted by password. All study data will be deleted at five years after the publication of results. Results will be disseminated in the form of publications and be included in Erin Smyth's PhD thesis.

Ethics approval:
This study has been approved by the University of Canberra Committee for Ethics in Human Research (Approval Number:20181527). If you, the participant, have any concerns you can contact the Human Ethics Committee: **E:** humanethicscommittee@canberra.edu.au; **T:** 02 6201 5220

Privacy statement
The conduct of this research involves the collection, access and/or use of your identified personal information. The information collected is confidential and will not be disclosed to third parties without your consent, except to meet government, legal or other regulatory authority requirements. A de-identified copy of this data may be used for other research purposes. However, your anonymity will at all times be safeguarded.

Further information:
If you have any questions, or you would like further information regarding the project titled**:** *Does ankle tape improve proprioception acuity immediately after application and following netball training?* please contact the Principal Researcher, **Erin Smyth** of the **Australian Institute of Sport** and **University of Canberra:**
PH: +61 420512039
EMAIL: u3098942@uni.canberra.edu.au

Appendix 7: Information for Parent/Guardian of Minor for Chapter 4

PARENT/GUARDIAN OF MINOR (UNDER 18 YEARS) PARTICIPANTS INFORMATION SHEET

Research Title: Does ankle tape improve proprioception acuity immediately after application and following netball training?

Principal Researcher:
Erin Smyth (0420512039, u3098942@uni.canberra.edu.au)

We would like to invite your child to participate in this research project. Choosing not to take part will not disadvantage your child in any way. Before you decide whether you want your child to take part, it is important for you to understand why the research is being done and what their participation will involve. Please take time to read the following information carefully and discuss it with others if you wish. Ask us if there is anything that is not clear or if you would like more information.

Aim:
The aim of this research project is to investigate whether ankle tape improves proprioception (position and movement sense) of the ankle.

Benefits:
The benefit will be the creation of current evidence to support or refute the common practice of taping/bracing to prevent ankle injuries.

What is involved?

Your child will undertake movement sensitivity (proprioception) testing at the ankle in a standing position using an AMEDA device. The AMEDA device consists of a footplate on a platform that can tilt to 5 possible positions resulting in ankle inversion movements between 10.5 and 14.5 degrees from the horizontal. Your child will be familiarised with the 5 positions in an introductory sequence where the different positions are set in order from smallest (position 1) to largest (position 5). This sequence is repeated 3 times. Following familiarization, the footplate, from its horizontal start position, will be moved to one of the 5 positions which your child will then be asked to identify. This will be repeated over 50 trials, each time returning to the start position, with each position presented 10 times in random order. The test is semi-automated and takes approximately 6 minutes to complete.

Then depending on which group your child has been assigned to, they will then have their ankles taped by a Sport and Exercise Physiotherapist or they will self-tape if that is their normal practice.

Proprioception will then be tested again, repeating the 50 trials

A Catapult local monitoring system tracker will then be fitted, and your child will participate in a normal training session or match.

Immediately after the training session, your child will repeat the 50 trials regardless of whether they tape, brace or neither.

The tape will then be removed, and your child will repeat the 50 trials.

Who are we recruiting?
Pre-elite netball players (17/U & 19/U state representatives and higher)

Withdrawal:
Your child may withdraw at any time without penalty.

Risks:
The risks to your child associated with participation in this study are minimal and are consistent with normal activities undertaken in everyday life in a clinical setting. For example, tripping on a carpet edge. To minimise risk, we will brief your child on standard procedures for conduct and safety within the research laboratory space.

Confidentiality:
Your child's results will be kept as confidential as is possible by law. All data will be kept in possession of the investigators. If the results of the study are published in a scientific journal, your child's identity will not be revealed. If your child wishes to withdraw from the study prior to publication of results their data will be removed from the study data. Participants will not be referred to by name during research reports or study discussions. All hard copy records will be stored in a locked filing cabinet in a private office. All computer records are restricted by password. All study data will be deleted at five years after the publication of results. Results will be disseminated in the form of publications and be included in Erin Smyth's PhD thesis.

Ethics approval:
This study has been approved by the University of Canberra Committee for Ethics in Human Research (Approval Number: 20181527). If you, the participant, have any concerns you can contact the Human Ethics Committee: **E:** humanethicscommittee@canberra.edu.au; **T:** 02 6201 5220

Privacy statement
The conduct of this research involves the collection, access and/or use of your child's identified personal information. The information collected is confidential and will not be disclosed to third parties without your consent, except to meet government, legal or other regulatory authority requirements. A de-identified copy of this data may be used for other research purposes. However, your child's anonymity will at all times be safeguarded.

Further information:
If you have any questions, or you would like further information regarding the project titled**:** '*Does ankle tape improve proprioception acuity immediately after application and following netball training?'* please contact the Principal Researcher, **Erin Smyth** of the **Australian Institute of Sport** and **University of Canberra:**
PH: +61 420512039
EMAIL: u3098942@uni.canberra.edu.au

Appendix 8: Informed Consent Form for Chapter 4

CONSENT FORM FOR PARTICIPANTS INVOLVED IN RESEARCH

Project:	Does ankle tape improve proprioception acuity immediately after application and following netball training?
Investigators:	Erin Smyth, Prof Gordon Waddington, Dr Phillip Newman, University of Canberra Research Institute for Sport and Exercise. Dr Michael Drew, Athlete Availability, Australian Institute of Sport. Dr Juanita Weissensteiner, NSW Office for Sport.

This is to certify that I, _____ am at least 18 years old and that I am voluntarily giving my consent to participate in the research project named above.

I certify that the investigation and my part in the investigation have been defined and explained to me by a member of the research team and I understand the explanation. A copy of the procedures of this investigation and a description of any risks has been provided to me and discussed with me.

- I have been given an opportunity to ask whatever questions I may have had and all such questions have been answered to my satisfaction.
- I understand that I am free to withdraw consent and to discontinue participation in the project or activity at any time, without disadvantage to myself.
- I understand that I am free to withdraw my data from analysis without disadvantage to myself.
- I understand that any data or answers to questions will remain confidential with regard to my identity.
- I am participating in this project of my own free will and I have not been coerced in any way to participate.

☐ I consent to participating in this research

Signature of participant: _____ Date: ____/____/____

Appendix 9: Informed Consent Form for Minors for Chapter 4

CONSENT FORM FOR PARTICIPANTS (MINOR) INVOLVED IN RESEARCH

Project: Does ankle tape improve proprioception acuity immediately after application and following netball training?

Investigators: Erin Smyth, Prof Gordon Waddington, Dr Phillip Newman, University of Canberra Research Institute for Sport and Exercise. Dr Michael Drew, Athlete Availability, Australian Institute of Sport. Dr Juanita Weissensteiner, NSW Office for Sport.

This is to certify that I, _____ hereby agree to give permission for my child _____to participate as a volunteer in the research project named above.

I certify that the investigation and my child's part in the investigation have been defined and explained to me by a member of the research team and I understand the explanation. A copy of the procedures of this investigation and a description of any risks has been provided to me and discussed with me.

- I have been given an opportunity to ask whatever questions my child or myself may have had and all such questions have been answered to my satisfaction.
- I understand that my child is free to withdraw consent and to discontinue participation in the project or activity at any time, without disadvantage.
- I understand that my child is free to withdraw their data from analysis without disadvantage.
- I understand that any data or answers to questions will remain confidential with regard to my child's identity.
- My child is participating in this project of her own free will and has not been coerced in any way to participate.

☐ I consent to my child participating in this research

Signature of Participant: _____ Date: ____/____/____

Signature of Parent or
Guardian of minor: (under 18 years) _____ Date:____/____/_____

Appendix 10: Human Ethics Committee approval for Chapter 5

Dear Erin

The Human Research Ethics Committee has considered your application to conduct research with human subjects for the project "20181551 - Injury prevention intervention development and implementation.".

The Committee made the following evaluation: **Approved**

The approval is valid until: 28/02/2019

The following general conditions apply to your approval. These requirements are determined by University policy and the ***National Statement on Ethical Conduct in Human Research*** (National Health and Medical Research Council, 2007).

Monitoring

You must assist the Committee to monitor the conduct of approved research by completing project review forms, and in the case of extended research, at least annually during the approval period.

Reporting Adverse Events

You must report any unexpected adverse events or complications that occur anytime during the conduct of the research study or during the follow up period after the research. Please refer these matters promptly to the HREC. Failure to do so may result in the withdrawal of the Ethics approval.

Discontinuation of Research

You must inform the Committee, giving reasons, if the research is not conducted or is discontinued before the expected date of completion.

Extension of Approval

If your project will not be complete by the expiry date stated above, you must apply for extension of approval. This must be done before current approval expires.

Retention and Storage of Data

University policy states that all research data must be stored securely, on University premises, for a minimum of five years. You must ensure that all records are transferred to the University when the project is complete.

Contact Details and Notification of Changes

All email contact should use the UC email address. You should advise the Committee of any change of address during or soon after the approval period including, if appropriate, email address(es).

Please do not hesitate to contact us via email humanethicscommittee@canberra.edu.au if you require any further information.

All the best,

Hendryk Flaegel
Research Ethics & Integrity
Research Services
University of Canberra
29/10/2018

Appendix 11: Information to Participants for Chapter 5

PARTICIPANT INFORMATION STATEMENT

Research Title: How are injury prevention interventions developed and implemented successfully to reduce injury rates in pre-elite netball athletes?

Principal Researcher: Erin Smyth (0420512039, u3098942@uni.canberra.edu.au)

We would like to invite you to participate in this research project. Choosing not to take part will not disadvantage you in any way. Before you decide whether you want to take part, it is important for you to understand why the research is being done and what your participation will involve. Please take time to read the following information carefully and discuss it with others if you wish. Ask us if there is anything that is not clear or if you would like more information.

Aim: The aim of this research project is to evaluate the implementation of the KNEE (**K**nee injury prevention for **N**etballers to **E**nhance performance and **E**xtend play) program, among coaches and physiotherapists of pre-elite netball athletes. The KNEE program is an injury prevention and performance enhancing program developed by Netball Australia.

Benefits: This study will make a valuable contribution towards developing and preventing injuries in pre-elite netball athletes.

What is involved?: You are being asked to participate in a research process called concept mapping.

The study will be conducted over 3-4 weeks and consist of three online activities.
Activity 1: brainstorm ideas about what the challenges are for coaches and physiotherapists of pre-elite netball athletes implementing the KNEE program. (30mins)
Activity 2: sort these ideas into groups of related concepts (30mins)
Activity 3: rate the relative importance of these ideas and the feasibility of netball Australia being able to successfully implement strategies to address them (30 mins)

Your participation will be spread over several weeks. After completing Activity 1 it will be two weeks before you are invited to participate in Activities 2 and 3 which you will be asked to do at the same time.

You will be able to participate as an individual at a time convenient to you. You will not need to meet with others somewhere in order to participate.

Participation is voluntary and anonymous. You will not be required to provide your name when you participate in the research. Other research participants will not be able to identify you or link any information or answers to you.

How do I give my consent to participate in this study?: You will be asked to consent to participate in this study at the beginning of Activity 1. This will require you to respond 'accept' on the first page of the online Concept Mapping system indicating you have read and understood this Participant Information Statement and you are happy to participate in the Concept Mapping process.

Adverse effects and withdrawal: We do not anticipate any adverse effects and you may withdraw at any time without penalty.

Confidentiality: The confidentiality of your data will be respected at all times. Only researchers directly involved in this project will see your data which will be kept for minimum of 5 years. Data is stored electronically on a secure site and any hard copies will be stored in a locked filing cabinet. Participants' names will not be associated with any aspect of this study; this will ensure anonymity during research and publication. Data will be collated so that an individual's information will not be able to be identified. Results will be disseminated in the form of publications and be included in Erin Smyth's PhD thesis.

Ethics approval: This study has been approved by the University of Canberra Committee for Ethics in Human Research (Approval Number: 20181551). If you, the participant, have any concerns you can contact the Human Ethics Committee: **E:** humanethicscommittee@canberra.edu.au; **T:** 02 6201 5220.

Further information: If you have any questions, or you would like further information regarding the project titled**:** '*How are injury prevention interventions developed and implemented successfully to reduce injury rates in pre-elite netball athletes?*', please contact the Principal Researcher,
Erin Smyth of the **Australian Institute of Sport** and **University of Canberra:**
PH: +61 420512039
EMAIL: u3098942@uni.canberra.edu.au

Appendix 12: Informed Consent Form for Chapter 5

Concept mapping consent form

Thank you for taking the time to participate in this Concept Mapping study to identify the barriers to coaches/physiotherapists of 17/U and 19/U state netball teams implementing the KNEE (**K**nee injury prevention for **N**etballers to **E**nhance performance and **E**xtend play) program with the teams they work with.

If you are not familiar with the KNEE program, please go to the KNEE website and familiarise yourself with the program before participating in this project.

You may be asked to offer your input in a variety of ways:

- by providing your ideas
- rating the ideas or sorting them into groups of similar themes
- by providing non-identifying information about yourself

Before participating in this Concept Mapping study, please read the Participant Information Statement (PIS) that was attached to the email you received inviting you to join the project. If you have not already read the PIS you can find a copy here.

It will be assumed that you are over the age of 18 and have read the PIS when you 'accept' to participate in this research below and start Activity 1.

Appendix 13: Human Ethics Committee approval for Chapter 6

AIS
Australian Institute of Sport

MINUTE

TO: Erin Smyth DATE: 27st March 2019

FROM: Tim Kelly (AIS Ethics Committee Secretary)

SUBJECT: Minor Variation to 'Injury profile of 17/U and 19/U netball athletes during and after National Championships' (20180404)

As Secretary of the AIS Ethics Committee, I acknowledge receipt of the Minor Variation Form for the above project on 27/03/19. While submission of the Minor Variation is received before the Ethics due date of 22nd March 2019, it cannot be considered by the AIS Ethics Committee before its scheduled meeting on 9th April 2019.

It is my understanding that due to circumstances beyond your control, the study is being conducted before 9th April, and is therefore not able to be considered by the AIS Ethics Committee. I have forwarded your submission on to the Chair of the Committee who has approved your amendment on the basis that the amendments are minor, and the study was granted full Ethics approval on 10th April 2018.

Please note, that this is not my preferred option, and that in future, the preference would be to have the AIS Ethics Committee review all amendments during scheduled meetings, no matter how minor. However, I accept the unusual circumstances, and the 'low risk' nature of the amendments.

The approval number for this project remains as: 20180404.

It is a requirement of the AIS Ethics Committee that the Principal Researcher (you) advise all researchers involved in the study of Ethics Committee approval and any conditions of that approval. You are also required to advise the Ethics Committee immediately (via the Secretary) of:

Any proposed changes to the research design,
Any adverse events that may occur.

Researchers are required to submit annual status report and final reports to the secretary of the AIS Ethics Committee. Details of status report requirements are contained in the 'Guidelines' for ethics submissions.

Please continue to note that the approval for this submission expires on 31st December 2020, after which time an extension will need to be sought.

If you have any questions regarding this matter, please contact me on (02) 6214 1791.

Yours sincerely,

T Kelly

Tim Kelly
Secretary, AIS Ethics Committee

Appendix 14: Information to Participants for Chapter 6

INFORMATION TO PARTICIPANTS

Research Title: Injury profile of 17/U and 19/U netball athletes during and after National Championships

Principal Researcher:
Erin Smyth (0420512039, erin.smyth@ausport.gov.au)

We would like to invite you to participate in this research project. Choosing not to take part will not disadvantage you in any way. Before you decide whether you want to take part, it is important for you to understand why the research is being done and what your participation will involve. Please take time to read the following information carefully and discuss it with others if you wish. Ask us if there is anything that is not clear or if you would like more information.

Aim:
The aim of this research project is to investigate injury and illness incidence in 17/U and 19/U Netball athletes during and one month following the 2019 National Championships.

Benefits:
This study will provide valuable insights into the injury profile of 17/U and 19/U pre-elite Netball athletes to help guide future injury prevention initiatives.

What is involved?
The study will be conducted over a 7 week period (28 March 2019 – 14 May 2019) and will consist of the following:

Online survey

You will be asked to complete two surveys (Low Energy Availability in Females Questionnaire & Pittsburgh Sleep Quality Index) on the 28th March. You will also be asked to complete the Health Problems Questionnaire at the start and end of the tournament as well as one and four weeks post tournament. It consists of four questions that ask whether you have experienced any health problems in the last week. You will be asked to provide the most accurate responses you can. These surveys will be accessible through the Athlete Management System (AMS).

AMS data entry

Your injury records and netball participation will be recorded on AMS by your team Physiotherapist and Netball Australia selectors. This data will be de-identified to protect your privacy.

Medical Care

Should you become unwell while in Brisbane for the tournament you will have access to the tournament doctor for a free consultation and will receive appropriate medical care. If the presenting complaint is suggestive of a possible infection. The doctor will conduct a history and physical exam and discuss the clinical findings, any relevant pathology and treatment that may be indicated. Your consent will also be requested for the outcome of the medical assessment to be included in the AMS and subsequent research project.

The care provided may include bulk billed pathology, radiological investigations or prescription of appropriate medications under the pharmaceutical benefits scheme. The pathology services will not cost you anything providing you have a Medicare card. However, medications on the pharmaceutical benefits schedule can attract a small fee from a local pharmacy. There will be no fee from the tournament doctor.

Common investigations for infective symptoms include a swab from the back of the nose, collection of sputum) sample, (mucus from a cough), faecal sample, or blood test. You will be free to accept or decline all or part of any investigations offered. The tests if indicated will help to inform what pathogen is causing the infection and direct individual treatment. When collated with other athletes' pathology results can contribute to our understanding of infection transmission within high performing sporting teams in competition.

At the end of the tournament, this will conclude the episode of medical care and a summary of your presentation will be sent to your nominated general practitioner who will then be responsible for continuing care. Your general practitioner will be able to contact the tournament doctor should they have any further questions.

Who are we recruiting?
We are recruiting all netball athletes participating in the 2019 17/U and 19/U National Netball Championships.

Adverse effects and withdrawal:
We do not anticipate any adverse effects and you may withdraw at any time without penalty.

Confidentiality:

The confidentiality of your data will be respected at all times. Only researchers directly involved in this project will see your AMS data which will be kept for minimum of 5 years. Data is stored electronically in the AMS and any hard copies will be stored in a locked filing cabinet. Participants' names will not be associated with any aspect of this study; this will ensure anonymity during research and publication. Data will be collated so that an individual's information will not be able to be identified. The AMS data utilised in this study may also be used in future studies. This research will be used to inform the design of injury and illness prevention programs for netball athletes in the future. Results will be disseminated in the form of publications and be included in Erin Smyth's PhD thesis. Follow up support will be provided by the student researcher Erin Smyth between Monday-Thursday, between the hours of 9am and 5pm.

Ethics approval:

This study has been approved by the Australian Institute of Sport Ethics Committee (Approval Number: 20180404). If you, the participant, have any concerns you can contact the secretary of the AIS Ethics Committee on 02 6214 1577.

Further information:

If you have any questions, or you would like further information regarding the project titled**:** *Injury profile of 17/U and 19/U netball athletes during and after National Championships*, please contact the Principal Researcher, **Erin Smyth** of the **Australian Institute of Sport** and **University of Canberra:**
PH: +61 420512039
EMAIL: erin.smyth@ausport.gov.au

Appendix 15: Information for Parent/Guardian of Minor for Chapter 6

INFORMATION TO PARENT/GUARDIAN OF MINOR (UNDER 18 YEARS) PARTICIPANTS

Research Title: Injury profile of 17/U and 19/U netball athletes during and after National Championships

Principal Researcher:
Erin Smyth (0420512039, erin.smyth@ausport.gov.au)

We would like to invite your child to participate in this research project. Choosing not to take part will not disadvantage your child in any way. Before you decide whether you want your child to take part, it is important for you to understand why the research is being done and what their participation will involve. Please take time to read the following information carefully and discuss it with others if you wish. Ask us if there is anything that is not clear or if you would like more information.

Aim:
The aim of this research project is to investigate injury and illness incidence in 17/U and 19/U Netball athletes during and one month following the 2019 National Championships.

Benefits:
This study will provide valuable insights into the injury profile of 17/U and 19/U pre-elite Netball athletes to help guide future injury prevention initiatives.

What is involved?
The study will be conducted over a 7 week period (28 March 2019 – 14 May 2019) and will consist of the following:

Online surveys

Your child will be asked to complete two surveys (Low Energy Availability in Females Questionnaire & Pittsburgh Sleep Quality Index) on the 28th March. They will also be asked to complete the Health Problems Questionnaire at the start and end of the tournament as well as one and four weeks post tournament. It consists of four questions that ask whether your child has experienced any health problems in the last week. Your child will be asked to provide the most accurate responses that they can. These surveys will be accessible through the Athlete Management System (AMS).

AMS data entry

Your child's injury records and netball participation will be recorded on AMS by their team Physiotherapist and Netball Australia selectors. This data will be de-identified to protect their privacy.

Who are we recruiting?
We are recruiting all netball athletes participating in the 2019 17/U and 19/U National Championships.

Adverse Effects and Withdrawal:
We do not anticipate any adverse effects and your child may withdraw at any time without penalty.

Confidentiality:

The confidentiality of your child's data will be respected at all times. Only researchers directly involved in this project will see their AMS data which will be kept for minimum of 5 years. Data is stored electronically in the AMS and any hard copies will be stored in a locked filing cabinet. Participants' names will not be associated with any aspect of this study; this will ensure anonymity during research and publication. Data will be collated so that an individual's information will not be able to be identified. The AMS data utilised in this study may also be used in future studies. This research will be used to inform the design of injury and illness prevention programs for netball athletes in the future. Results will be disseminated in the form of publications and be included in Erin Smyth's PhD thesis. Follow up support will be provided by the student researcher Erin Smyth between Monday-Thursday, between the hours of 9am and 5pm.

Consent:

Your child will be asked to complete a questionnaire on their smartphone. Prior to this they will be asked to provide your consent, name and contact email. Can you please communicate with your child prior to 28th March 2019 whether you give your consent for them to participate in this research project.

Ethics Approval:

This study has been approved by the Australian Institute of Sport Ethics Committee (Approval Number: 20180404). If you, the participant, have any concerns you can contact the secretary of the AIS Ethics Committee on 02 6214 1577.

Further information:

If you have any questions, or you would like further information regarding the project titled**:** *Injury profile of 17/U and 19/U netball athletes during and after National Championships*, please contact the Principal Researcher, **Erin Smyth** of the **Australian Institute of Sport** and **University of Canberra:**
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Appendix 16: Informed Consent Form for Chapter 6

Injury profile of 17/U and 19/U netball athletes during and after 2019 National Championships

Principal Investigators: Ms Erin Smyth (PhD Scholar, AIS/UC), Dr Michael Drew (AIS), Prof Gordon Waddington (AIS/UC), Dr Juanita Weissensteiner (AIS), Dr Philip Newman (UC), Dr Laura Juliff (Netball Australia), Ms Alanna Antcliff (Netball Australia)

You are invited to take part in this research project.

Please read the **Participant Information Form** carefully as this will tell you about the research project and explain what is involved. This will help you decide if you want to continue and take part.

Ask questions about anything that you don't understand or want to know more about. Before deciding whether or not to take part, you might want to talk about it with a relative, friend or healthcare worker.

Participation

- Participation in this study is entirely voluntary.
- You're not obliged to participate and if you do, you can withdraw at any time without penalty or prejudice.
- To participate, we would like you to complete the online questionnaires: 'Low Energy Availability in Females Questionnaire', Pittsburgh Sleep Quality Index' and 'Health Problems Questionnaire'.
- Your participation, personal details and results will be strictly confidential and only the Principal Investigators above will have access to the information.

By ticking the 'I ACCEPT' or 'My Parent or Guardian ACCEPTS' option below you are telling us that you or your Parent or Guardian:

- Understand what you/they have read.
- Consent to take part in the research project.
- Consent to participate in the research processes that are described.
- Consent to use your personal and health information as described.
- Understand that you are free to not answer specific items or questions.
- Understand that any data or answers to questions will remain confidential with regard to your identity.
- Certify to the best of your knowledge and belief, you have no physical or mental illness that would increase the risk of participating in this project.
- Are participating in this project of your own free will and have not been coerced in any way to participate

☐ I ACCEPT (If you do not accept, please exit the browser)

Minors (Please complete if under 18 years)

☐ My Parent or Guardian ACCEPTS (If they do not accept, please exit the browser)

Parent/Guardian full name: _____

Parent/Guardian email address: _____

Appendix 17: Foot blister advice sheet and pack

Author: Ruth Fazakerley
(AIS Registered Nurse)

Blister Prevention & Care for Athletes

Introduction

One of the most common injuries that athletes sustain that has the potential to lead to loss of time from training and competition are blisters.

They can range from being an uncomfortable nuisance to requiring hospitalisation and the administration of intravenous antibiotics for spreading infection which can cause significant time out of play.

Being aware of how to avoid blisters and being prepared to safely self-mange any blisters immediately they occur can help prevent any complications from affecting your performance.

What are blisters?

Blisters occur from friction or rubbing of the skin causing one layer of skin to separate from another. This creates a pocket which fills with fluid, causing pain and inflammation.

The common types of blisters you will see are:

- **Closed**
- **Open or torn**
- **Blood blister**
- **Deep blisters under a callus**
- **Infected blister**

Common reasons that blisters occur in athletes:

- Returning to training or competition after a break
- Increased frequency and intensity of training loads or games such as camps or nationals
- New orthotics or shoes
- Poorly fitting shoes or orthotics
- A build-up of unhelpful callus

Preventing Blisters includes:

- Recognising when there is an increased likelihood of blisters occurring and take preventative action.
- Wearing in new shoes or a change of orthotics slowly by not wearing at every training or game.
- Wearing the right socks, choose socks that will wick moisture away from the foot, keeping it dry.
- Avoiding seams on your socks that can rub.
- Keeping your feet dry; by avoiding wearing damp socks, changing into clean dry socks if you have multiple games or training sessions in one day.
- Wash your feet, dry well and air in between sessions.
- Use a powder to promote dryness, Curash powder is a good one it contains cornstarch and zinc and absorbs excess perspiration. Apply to clean and dry skin.

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- Stop and readjust when you feel a hot spot, this may be readjusting socks/ shoes/orthotic or applying a protective cover such as bandaid or fixomull.
- Check that your shoes are the correct fit, not too tight (causing pressure) or too loose aiding slippage (causing friction).
- Manage callused areas by preventing the build-up of unhelpful callus (see below).
- Cover the problem spots on your feet by protecting those areas that are vulnerable to friction with a protective covering such as Fixomull or Hypafix, adhesive moleskin. ***Tip: when using Fixomull/Hypafix curve the corners to reduce the risk of the material catching and rolling causing another area of pressure***

Callus management

Callus build up occurs on those area of the body that are regularly subjected to friction. These thickened areas of skin protect us against surface friction and help to reduce the incidence of blisters. However there are times when the build-up of callus can do more harm.

A thick, dry and cracked or abnormally shaped callus (one that does not conform to the normal anatomical contour of that part of the body) can transfer pressure and friction to the deeper skin layers causing a deep fluid filled blister. If left untreated the callus itself becomes the blister hood and if torn can result in a deep painful and open blister.

The management of your callus includes the recognition of unhelpful callus formation and its removal.

For netballers the most common areas of callus formation are:

- Along the middle edge of your large toe.
- At the base of your large toe over the ball of your foot.
- Over your heels.

Indications that a callus requires trimming can include:

- A blister is visible under the callus.
- The callus has developed an abnormal shape and hardness sometimes displayed as a palpable ridge.
- The callus is dry and cracking.
- Small dark spots appearing under the callused area which may be petechial haemorrhages, these are tiny areas of bleeding deep in the tissue caused by pressure from the thick callus.
- The callus is thick and yellowing.
- Localised pain at the site of the callus after exercising which may be a burning sensation.

Be responsible for your foot care and manage callused feet before problems occur.

How to removal excess callus:

For the effective safe removal of thickened problematic callus seek the help of a podiatrist or other health professional experienced in callus removal.

They will use a special tool to shave the excess callus to a more normal coverage of thickened skin. Athletes can then assist callus maintenance by the regular use of a foot file to shave the area and prevent reoccurrence of excess callus.

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Foot files are like large emery boards although much coarser, they can be purchased for approximately $8 to $12 from most chemists and supermarkets that have a foot care section. The Scholl brand of foot file can be purchased from Priceline, but there are several good foot files you can choose from.

Eulactol Scholl heel balm is one of many products on the market that help to soften calluses. It is particularly helpful in preventing the cracking that occurs from the callus becoming dry. Applying the balm at night and wearing socks for several consecutive nights is very effective.

Closed blister management

The usual management of a closed fluid filled blister is to leave it alone and allow the reabsorption of the fluid to occur naturally.

Normally there is no need to puncture the fluid filled blister unless it is large, painful or likely to be further irritated. For elite athletes unless a blister occurs at the same time as a planned break, this option is not considered, the risk of leaving the blister closed and continuing to exercise can lead to a traumatic tearing of the blister hood causing more discomfort and potential for infection.

The preferred option for athletes is to remove the fluid under aseptic conditions in order to prevent further trauma and reduce the incidence of infection.

It is important to have the correct equipment do this.

Open blister management

If a blister hood has torn and the fluid has escaped, the remaining skin from the blister hood should be removed carefully and betadine or another antiseptic applied to prevent infection. The open blister should be covered with a suitable protective dressing to provide comfort and avoid contamination of the wound.

- An **adhesive foam dressing** (eg Allevyn gentle border, smith&nephew) will provide comfort from the padding and absorb discharge.
- A **blister plaster** will aid healing by providing a moist wound environment and protect against infection.

Blister Plasters are available in Pharmacy's and some supermarkets

A donut either of silicone gel or foam can be placed over the dressing to remove direct pressure on the healing wound and reduce discomfort while continuing activity.

Analgesia can be taken to relieve pain, and ice applied to reduce swelling and discomfort.

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You should **not use shared pools** such as recovery or swimming pools when you have a healing open blister.

Signs & Symptoms of infection

The most common complication of blisters is infection, and for athletes this can develop quickly and requires prompt attention. Continuing to exercise with an untreated infected blister, can lead to the infection spreading rapidly beyond the blister.

If you experience any of the following when you have a blister seek medical advice immediately.

- Pain which can be throbbing and keep you awake at night.
- Pus or discharge from the wound.
- Spreading redness around the blister that may track away from the blisters edge.
- Area around the blister feels warm or hot to touch.
- Feeling unwell.
- Having a raised temperature.
- An elevated resting pulse.
- Discomfort in the groin on the affected side.

By seeking early diagnosis and treatment you can avoid unnecessary removal from play or training. Treatment may include the application of local antimicrobials and sometimes oral antibiotics to eliminate the bacteria, in addition a wound swab may be taken to discover the particular organism causing the infection. Dressings to keep the area protected and covered will be used.

Blisters commonly occur at the edge of a thickened callus. This open blister has spreading erythema (redness) which is tracking away from the blisters edge, this indicates infection which requires medical intervention.

Marking the edge of the redness can help in assessing whether the infection is responding to treatment.

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If you self-manage a blister while on camp always discuss this with your team support, who can provide any further assistance if needed.

These items should be included in a Blister Care Pack to help you to pierce a closed blister safely.

- ✓ Alcohol wipes
- ✓ Betadine wipes
- ✓ Skin prep wipes
- ✓ Gauze swabs
- ✓ Splinter probes (used instead of sterile needles to comply with no needle policy for athletes)
- ✓ Assorted Band-Aids
- ✓ Plastic waste bag

How to use the Blister Pack to pierce a closed blister:

To pierce a closed blister safely to reduce the incidence of infection follow these instructions:

- ✓ Wash your hands
- ✓ Clean the area well with the alcohol swab
- ✓ Using the splinter probe pierce the blister hood several times to allow the evacuation of fluid from the blister this will aid continued drainage.
- ✓ Gently squeeze out the blister fluid and use the gauze remove the fluid
- ✓ Thoroughly apply betadine (if no allergy to iodine)
- ✓ Cover with Band-Aid, secure by using skin prep to surrounding intact skin to aid adherence and cover with fixomull tape
- ✓ Carefully recap the splinter probe and dispose of safely
- ✓ Wash hands & dispose of used supplies in plastic bag provided

Use each splinter probe for a single blister treatment only