Improving the Design and Implementation of New Zealand's NetballSmart Injury Prevention Programme

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ABSTRACT

Netball is the most popular female sport played in New Zealand and has a high incidence of lower extremity injuries. Knee injuries are common, often keeping players from participating for substantial periods of time. A collaborative approach between the Accident Compensation Corporation (ACC) (a no-fault national insurance system), Netball New Zealand (NNZ) and respected members of the netball community led to the development of the NetballSmart Injury Prevention Program (NIPP). This collaborative group identified key areas of focus for the programme, with two priority areas being 'Smart movement' and 'Smart Warm-up". Unfortunately, many national injury prevention programmes (IPPs) have failed to be effectively implemented amongst their community, leading to poor adoption and subsequent ineffective change. Therefore, the aim of this thesis, was to improve the design and implementation of New Zealand's NIPP.

The thesis is comprised of eight chapters, with chapters two through seven written in a manuscript style. The narrative of the thesis somewhat follows the four steps of the injury prevention model "sequence of prevention stages" (van Mechelen, Hlobil & Kemper, 1992). The thesis aim was achieved by taking a pragmatic approach to undertaking research in a real-world setting, starting with a narrative review of the literature on IPP implementation. The review clearly identified common themes for barriers and facilitating factors that affect implementation of an IPP. The four themes identified were: ***The importance of stakeholders***; ***The importance of collaboration***; ***Relevant content***; ***Implementation.*** From these themes a suggested 6-step practical guideline for effective real-world dissemination of the NIPP over the next three -years was developed.

The practical guideline highlighted the need to better understand common netball injuries age groups most at risk of injury and seasonal injury patterns. This improved the focus of NIPP resource and educational workshop content design and guided the dissemination plan. Ankle and knee injuries were identified as the most prevalent injury body sites and a ten-year review of the ACC injury data for these two body areas was evaluated. Key findings were that ankle and knee injuries had increased the most in 10-19-year-olds (ankle 37-84% increase and knee 49-133% increase), but that injuries in 20-24-year-olds still represent the highest cost and continued at a higher rate than in younger players. Spikes in injury were seen and are likely associated with intense periods of trialling and tournament play.

As Anterior Cruciate ligament (ACL) injuries remain a serious problem within netball and are a key focus in the NIPP. An investigation of injury mechanism specific to ACL injury was also undertaken. Twenty-one ACL injuries videoed during games were analysed by a group of experts, who identified new insights into the mechanism and player behaviours associated with ACL injury in netball. Firstly, many of the injured players were receiving the ball high in the air and opting to bring the ball low (at/or below pelvis level), which could theoretically subject the knee to increased abduction and rotation moments. Secondly, that the players were turning their head 45-90^{o} away from the injured limb, looking for their next pass rather than bringing their whole body around for the pass before completing their landing. This likely created some action-reaction rotational torque through segments of the body increasing knee injury risk. The findings of this study led to the introduction of new practical coaching tips in the NIPP for reducing injury-risk in players.

The thesis then investigated the effects of two key NIPP neuromuscular training resources, the NetballSmart Dynamic Warm-up and the adapted Power Warm-up, on physical performance measures and landing ability in youth netball players. A 12-week cluster randomised control trial, involving 12 secondary school netball teams, with pre-and post-physical outcome measure was undertaken. The key finding of this study was that both warm-ups improved all landing technique outcomes and several of the performance measures (strength and balance) and neither warm-up was better than the other. Evidence of performance enhancement increased the legitimacy of the warm-up programmes within the netball community and facilitated uptake, whilst offering suggestions for further training exercises to potentially reduce injury risk and increase performance.

Finally, commentary was made on how the research of this thesis was practically applied to the real-world design and implementation of the NIPP over the first three-years of the programme. All the studies add to our knowledge regarding the nature of netball injury and how guided research can improve the design and implementation of a national IPP. Future research building upon the ideas presented in this thesis is recommended to further develop the design and adoption of the NIPP in the forthcoming years and leverage the programmes early success.

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ATTESTATION OF AUTHORSHIP

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

Suzanne Belcher

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COAUTHORED PAPERS

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CHAPTER 1: INTRODUCTION

Participation in netball is high worldwide, being played in over 70 countries (Hetherington, Hardcastle, Visentin, & Bird, 2009). In 2018 Netball New Zealand (NNZ) reported a community of 145,453 affiliated netball members, with 82,778 (57%) of these members between 10-19-years of age (NNZ affiliated members stats, 2018). As with many sports in New Zealand, NNZ has had a long-standing relationship with the country's Accident Compensation Corporation (ACC) (a no-fault national insurance system) (Fulcher, Carlson, Mitchell, Bizzini, & Dvorak, 2018; King et al., 2019). This collaboration has primarily focused on the development and delivery of the NetballSmart nationwide injury prevention programme (IPP), which commenced in 2017. The NetballSmart programme was developed to reduce injuries in netball and subsequently decrease the financial strain of these injuries to the ACC, whilst helping to develop physically capable netball participants that will hopefully wish to stay playing the game for longer.

The physical demands of the netball game:

In netball seven players from each team are on court and must move within restricted areas based on their designated position. To be successful, players must excel in the physical demands of the game including: rapid acceleration/deceleration, explosive change of direction (COD), catching, passing, powerful jumps and well-balanced landings often on a single-leg (McManus, Stevenson, & Finch, 2006; Stuelcken, Greene, Smith, & Vanwanseele, 2013; Williams & O'Donoghue, 2005). Sudden bouts of speed, agility, power and strength are required in Netball (de Villiers & Venter, 2014), but it is the ability to control these high-intensity movements throughout the 60 minutes of the game that is important to performance and avoiding injury (Bailey, Gastin, Mackey, & Dwyer, 2017), One of these high intensity movements is jumping. Lavipour (2011), found that on average netball players will perform one jump per minute during a netball game, landing unilaterally 67% of the time. Another frequently performed movement is COD, which can occur approximately every three seconds during a netball match (Davidson & Trewartha, 2008; Thomas, Comfort, Jones, & Dos'Santos, 2017b). Some netball positions require players to jump and change direction more frequently in the game and may be at higher risk of lower extremity injury as a result. Centre (C), Wing-attack (WA) and Goal-attack (GA) players average 78 jumps a game, whilst the Goal-shooter (GS), Goalkeeper (GK), Goal-defence (GD) and Wing-defence (WD) average 46 jumps (Lavipour, 2011). Similarly, Fox et al., (2013) found the C and WA positions performed more jumps, combined jump-turning motions and COD movements than other positions. A key rule that separates netball from similar sports is that players can only take a maximum of one and half steps whilst in possession of the ball, therefore they must rapidly decelerate and stop in order not to violate this rule (Hopper, Haff, Joyce, Lloyd, & Haff, 2017). This rapid reduction in horizontal velocity, whilst attempting to maintain balance, poses a significant injury risk to the lower extremity, specifically the ankle and knee joints? (McManus et al., 2006; Stuelcken et al., 2013)

Injury epidemiology and injury mechanisms in netball

Previous research would suggest ligament sprain/strain injuries to the ankle and knee were the most common in netball, with ankle sprain being the most frequent and Anterior Cruciate Ligament (ACL) the more serious injury (Downs, Snodgrass, Weerasekara, Valkenborghs, & Callister, 2021; Flood & Harrison, 2009; Hume & Steele, 2000; Joseph, Naughton, & Antcliff, 2019; Pillay & Frantz, 2012). Studies indicate that severe-moderate injuries are more prominent amongst older players, particularly ACL or Achilles tendon rupture, creating large financial costs to insurance companies (Downs et al., 2021; Flood & Harrison, 2009; Fulcher et al., 2018; King et al., 2019). However, in comparison the youth aged netball players often have a greater overall number of injuries per year and will most likely seek out hospital diagnosis or admission for fractures (Downs et al., 2021; King et al., 2019). Sutherland, Clatworthy, Fulcher, Chang, and Young (2019), reported in New Zealand a growing trend of increased ACL reconstructions amongst females aged 15–19 years in all sports, with the incidence increasing by 120% in the last decade, compared with 53% in females aged 20–24 years. These findings suggest a pattern of increasingly serious knee injury amongst younger netball players, which will inevitably require action to reduce any further escalation.

A variety of injury prevention models have been previously reported that aim to identify and prevent injury by following strategic processes. One of the early, frequently cited models is the “sequence of prevention” (van Mechelen, Hlobil, & Kemper, 1992). This model consists of four steps: (1) Establishing the extent of the injury problem; (2) Identifying the key risk factors and mechanisms of injury; (3) Introducing preventive strategies to mitigate the risk of injury and (4) Evaluating the effectiveness of preventive strategies by repeating Step 1. Later an extension of this model was proposed by Finch (2006), in the form of the Translating Research to Injury Prevention Practice (TRIPP) model. This model extension offered some discussion on the importance of implementation strategies and the need for evaluation/feedback from the community the IPP was targeting. However, subsequent research has identified a variety of limitations in the existing injury prevention models and endeavoured to improve on these shortcomings. One important limitation was that the models described injuries as linear mechanisms and that future models needed to recognise the multifactorial nature of injury (Bittencourt, Meeuwisse, Mendonca, Nettel-Aguirre, Ocarino & Fonseca, 2016; Meeuwisse, Hagel & Emery, 2007; O’Brien, Finch, Pruna & McCall, 2019). Other models lacked clear real-world operational steps (Padua et al. 2014; Roe et al. 2017); and failed to incorporate player workloads (Windt and Gabbett 2017). The consensus from previous studies is that the applicability and relevance of each model is context dependent. Most IP models appear to be geared towards the conduct of injury prevention research (van Mechelen et al. 1992; Finch 2006), rather than offering practical processes for real-world implementation and/or management of injury (O'Brien, Finch, Pruna & McCall, 2019). This could lead to a failure of the IP model meeting the needs of the target community and a reduction in dissemination and sustainability (Donaldson et al., 2017).

One step or process all IP models recognise is that injury surveillance/databases provide essential information when strategizing an IPP implementation plan (Ekegren, Gabbe, & Finch, 2016; Tabben, Whiteley, Wik, Bahr, & Chamari, 2019; van Mechelen, Hlobil, & Kemper, 1992). Epidemiological research can guide the focus of an IPP by identifying which body areas are most at risk, target the content of a programme based on the audience and distinguish any seasonal injury patterns that exist (Brooks & Fuller, 2006; van Mechelen, 1997). Much of the previous netball injury surveillance research, has been collected using quite inconsistent and varied methodologies to record classification, mechanism, and the place/environment of injuries, therefore decreasing the ability to compare injury data across seasons, between teams or individuals (Brooks & Fuller, 2006; Downs et al., 2021; Tabben et al., 2019). Some of the published netball injury data tracks individual teams over a limited period-of-time, rather than reviewing injury data on a national level (Hopper, Elliott, & Lalor, 1995; Langeveld, Coetzee, & Holtzhausen, 2012). Often these studies fail to account for training injuries or focus on injuries obtained at competition events only. Some initial studies have investigated larger national cohorts of injury data over several years in Australia (Flood & Harrison, 2009; Joseph et al., 2019) and New Zealand (King et al., 2019). These studies have limitations, such as being unable to identify a comprehensive proportion of the population's injuries (for example only capturing data from those who have attended an emergency department) or to garner quality participation data to estimate injury rate. These study limitations are common ones identified in injury surveillance research (Downs et al., 2021; Knowles, Marshall, & Guskiewicz, 2006). The benefits of utilising a detailed national injury database such as that of the ACC, cannot be underestimated. The ACC requires little immediate financial input from injured parties, so it is common for even minor sport training and game injuries to be registered, capturing a greater spread of injury variety and population (Fulcher et al., 2018; King et al., 2019). However, even with a relatively robust national data system such as that of the ACC, limitations do exist. One of which is that the ACC uses read codes as a system of injury identification, which are prone to being inconsistently used by practitioners. For instance, for an ACL knee injury a physiotherapist can only use the read code knee sprain, whereas surgeons can use the read code ACL. It can often take several months for the injury code to be correctly changed to accurately identify the injury and on occasion it remains incorrect. This obviously reduces the accuracy of the data analysed within an epidemiology study.

In terms of the magnitude of the sports injury problem in NZ, the ACC focus primarily on the total number of injuries and subsequent cost. Similarly, it uses a reduction in the count of injuries as a key outcome when evaluating the success of an IPP. Injury count therefore remains an important measure to be considered when interpreting epidemiological data, in NZ. Injury research that can also express a rate of injury offers more valid information to guide IPP resources, determine the priority audiences for education and to highlight which age groups require further investigation on cause of injury and targeting for prevention strategies. Use of national affiliated member numbers obtained from NNZ annually as a denominator against the ACC data, allows a determination of annual incidence rate per year and valid evaluation of changes over time. Larger national injury databases also offer the opportunity to evaluate any existing patterns throughout concurrent seasons. An instance when seasonal data may be of use is in youth sports, where clustered bouts of tournaments, with high game-play hours are common in some months of junior level competition. Youth have been shown to sustain 24% of their injuries during the course of tournaments and a higher incidence during game play than training (Hopper, 1997). Exploring injury patterns over the season could reveal whether there is a noticeable increase in injury over tournament months, particularly amongst youth age-groups. This could lead to improved design of IPPs and the national structure of the competition. Unfortunately, very few studies worldwide have investigated the epidemiology of netball injuries, especially on a nationwide scale.

A lower extremity injury of particular concern in netball, due to the long-term consequences and cost of rehabilitation, is to the ACL (Downs et al., 2021; Fulcher et al., 2018). The risk factors and mechanisms of ACL injury have been extensively studied within other team sports, but not netball (Boden, Sheehan, Torg, & Hewett, 2010; Chappell & Limpisvasti, 2008; Hewett, Ford, Xu, Khoury, & Myer, 2017). Yet, netball is considered to have a relatively high rate of non-contact lower extremity injuries, with ACL rupture being the most-costly (in loss of training/game hours, future risk of physical impairment and financial cost to insurers) (McManus et al., 2006). It is suspected that some netball players retire early from the sport because of serious knee injuries (Hopper et al., 1995; Otago & Peake, 2007). Poor technique when performing landing movements and COD during netball training and games, has been linked to knee injury risk and reduced game performance in all age groups (Fox, Spittle, Otago, & Saunders, 2012; McManus et al., 2006). It is believed that abnormal joint loading due to poor jump-landing and COD, places the lower extremity at risk of injury (Root, Trojian, Martinez, Kraemer, &. DiStefano, 2015). Examples of poor technique when landing include limited knee flexion (<30º), excessive hip adduction or internal rotation and knee valgus collapse (Hewett, Ford, Hoogenboom, & Myer, 2010). As noted earlier some positions in netball will have to jump and change direction more frequently in the game and may be at higher risk of lower extremity injury. In a study by (Otago, 2004), players in the WA and C positions represented (81%) of the ACL injury cases and it is these positions that perform a higher frequency of multi-directional movements and jumping during play when compared to their teammates (Fox, Bonacci, McLean, Spittle, & Saunders, 2014; Fox, Spittle, Otago, & Saunders, 2013).

Certain intrinsic and extrinsic risk factors in players can also put them at greater risk of lower extremity injury (Meeuwisse, Hagel & Emery, 2007). Some of the recognized risk factors amongst female players include: previous injury, muscle strength imbalance, poor balance and poor postural stability (Murphy, Connolly, & Beynnon, 2003). Along with reduced knee flexion, excessive hip adduction or internal rotation and knee valgus collapse during landing tasks, it has been reported that females also rely on quadriceps eccentric work more compared to their male counterparts (Hewett et al., 2010; Malinzak, Colby, Kirkendall, Yu, & Garrett, 2001; Mokhtarzadeh et al., 2017). These differences in landing technique are especially evident in youth (Jacobs, Uhl, Mattacola, Shapiro, & Rayens, 2007). This is in-part due to reduced neuromuscular control, that appears to occur just after the post-pubertal age, worsening with maturation, if training is not undertaken to improve it (Myer et al., 2009). One reason for this lack of neuromuscular control may be an increase in limb-length following maturation. The increase in moment arm and resulting increase in joint load, in the absence of adequate hamstring and lower-limb strength may cause young females to land in a more extended knee position (Decker, Torry, Wyland, Sterett, & Richard Steadman, 2003; Podraza & White, 2010). These alterations with growth are coupled with hormonal changes in preadolescence, that may increase ligament laxity by affecting the collagen structure through the release of Relaxin and Oestrogen (Belanger, Burt, Callaghan, Clifton, & Gleberzon, 2013). Reduced quadriceps strength and flexibility often found in female athletes theoretically leads to decreased knee function, affecting performance and predisposing players to injury (Hughes & Dally, 2015; Pappas, Zampeli, Xergia, & Georgoulis, 2013). Ferreira and Spamer (2010), showed a reduction in quadriceps flexibility and strength in females as the netball season progressed. Another cited factor that could exacerbate the risk of ACL and lower extremity injury hip musculature weakness (Powers, 2010). If the hip musculature is weak the hip may move into adduction during loading, which can place the knee into a valgus position (Jacobs et al., 2007; Powers, 2010). Finally, landing with $<30^{o}$ knee flexion is also likely to increase ground reaction forces (GRF), by putting the muscles of the lower extremity in a disadvantageous position to safely absorb landing forces (Podraza & White, 2010). Landing forces in youth netball players can be as high as 2.3 times bodyweight in dynamic vertical (DVJ) jump tasks and 1.9 times bodyweight in single leg landing tasks (Hopper et al., 2017). Repeated high-impact loading associated with jumping is likely to contribute to the incidence of acute and overuse lower extremity injuries, in both recreational and high-performance netball players (Hopper, 1997; McManus et al., 2006; Smartt & Chalmers, 2009).

Current research has identified trunk motion during COD (cutting motions), mid-flight jumping, and on-landing can increase the risk of lower-extremity and ACL injury (Davis, Hinshaw, Critchley, & Dai, 2019; Hinshaw et al., 2019; Sheehan, Sipprell, & Boden, 2012; Song, Li, Hughes, & Dai, 2021). Limited trunk flexion with the participants centre of mass (COM) too far back and increased trunk lateral bending towards the injured leg is associated with increased risk of ACL injuries (Davis et al., 2019; Della Villa et al., 2020; Hinshaw et al., 2019; Song et al., 2021). In those injured, trunk axial rotation away from the injured leg is more frequent than rotation towards the injured leg (Song et al., 2021; Stuelcken et al., 2013). Finally, perturbation (contact, potentially by an opposing player) to the upper-body and trunk during mid-flight and on landing, has been revealed to increase the risk of ACL injury (Della Villa et al., 2020; Song et al., 2021; Waldén et al., 2015; Yom, Simpson, Arnett, & Brown, 2014). Netball by nature is a ball sport that involves throwing, catching and often will require a player lean quite far outside their COM to reach the ball, which in turn necessitates a level of integrated trunk control to assist balance (Fox et al., 2014; Thomas et al., 2017b; Zazulak, Hewett, Reeves, Goldberg, & Cholewicki, 2007). For dynamic weightbearing motions to be successful, the load transfer and muscle power for trunk and lower extremity movements must be synchronously coupled (Davis et al., 2019; Vleeming, Pool-Goudzwaard, Stoeckart, van Wingerden, & Snijders, 1995). Trunk and lower extremities act as a kinetic chain, so the motion of the trunk may influence the motion and therefore loading of the knee (Hewett, Torg, & Boden, 2009). Therefore, assessment of whole-body movement behaviours during explosive netball motions (jump-landing, COD), rather than just the lower-limb may be necessary. Understanding what occurs at the lower-limb when turning the head to look in the opposite direction to the rest of the upper-body or what happens when a player drops the ball to the side, is therefore essential to improving landing ability (Fox et al., 2012; Padua et al., 2015). There have been several video analysis studies investigating ACL injury in team sports handball (Koga et al., 2010; Olsen, Myklegust, Engebretsen, & Bahr, 2004), rugby (Montgomery et al., 2018), football (Della Villa et al., 2020; Waldén et al., 2015), basketball (Krosshaug et al., 2007a), American (Johnston et al., 2018) and Australian Football (Cochrane, Lloyd, Buttfield, Seward, & McGivern, 2007). Stuelcken, Mellifont, Gorman, and Sayers (2016), are the only researchers to have systematically analysed the biomechanics of ACL injury in netball. Yet, there remains a lack of clear understanding about the injury mechanism and what constitutes risky movement patterns/behaviours in the netball game. More importantly, ACL video analysis research has failed to factor in many behavioural characteristics/actions and external factors (effect of perturbation from opposing players) that may have a significant effect on the risk of knee injury in netball (Mehl et al., 2018; Nessler, Denney, & Sampley, 2017). Further examination and understanding of knee injury mechanics in netball could help inform future NMT programmes, IPP educational coaching tools and biomechanical evaluation.

<u>The NetballSmart injury prevention programme (NIPP).</u>

In 2018 the ACC reported a 33% increase in lower extremity netball injuries from 2008 to 2017, costing an extra $4,669,457 in 2017 compared to 2008 ($15,641,871). This included a

57% increase in ankle and knee injury claims for 10-19-year-olds (New Zealand Accident Compensation Corporation, 2018). ACC therefore partnered with Netball New Zealand (NNZ) in a three-year funded project to create the national NetballSmart injury prevention programme (NIPP). The main objective of which was to decrease injuries to all netball players and develop physically capable competent movers who can cope with the demands of the game. A collaborative approach between the national sports organisation (NSO) NNZ, regional sports organisations (RSOs) (5 national netball zones and their centres), schools and programme leaders identified key principal areas of focus for the programme. Two of the identified programme priority areas were 'Smart movement' and 'Smart Warm-up". The NIPP 'Smart movement' resources and educational programmes focused on improving technique in fundamental netball movements associated with performance and injury risk (jump-landing, COD, stopping/decelerating). The 'Smart Warm-up' project integrated the various warm-up resources across the NNZ coaching education framework and utilised NetballSmart Development Officers to teach coaches how to effectively use the warm-up as an IPP.

The NetballSmart dynamic warm-up (NSDW), a modified version of the FIFA 11+ warm-up, was one of the first practical resources implemented through the NIPP. The NSDW was initially created in 2015 (Appendix I) but was not largely adopted by the netball community, primarily due to a lack of funding available for dissemination of the programme. The NSDW was re-designed in 2017 and split into 4 parts, strengthening, running warm-up, dynamic preparation (dynamic strengthening and early plyometric movements) and netball specific preparation (deceleration, agility/cutting motions and single-leg control landing) (Appendix II). Further, adapted NetballSmart warm-up programs were created throughout the first 3-year of the programme the most utilised of which is the shortened Power Warm-up (PWU) (Appendix III). The original FIFA 11+ was created by an international group of experts to reduce football injury, however as the physical demands of netball differ to those of football the NSDW was modified. The NSDW has an increased emphasis on jump-landing technique and control of fast decelerating movements, to better prepare players safely for the game and improve control of high injury risk movements (Root et al., 2015; Stuelcken et al., 2013; Stuelcken et al., 2016)

Neuromuscular and plyometric IPPs such as the FIFA 11+, can reduce injury by 30-60% and improve landing biomechanics when performed at least twice weekly (Al Attar, Soomro, Pappas, Sinclair, & Sanders, 2017; Impellizzeri et al., 2013; Steffen et al., 2013). Additionally, interventions similar to the NSDW, inclusive of both strength and plyometric training have been shown to significantly improve landing technique and reduce lower extremity injury risk in females (Hadzovic, Ilic, Lilic, & Stankovic, 2020; Myer, Ford, Palumbo, & Hewett, 2005; Yoo et al., 2010). The inclusion of trunk stabilisation, posterior chain muscle (hamstrings, gluteals, gastrocnemius) strengthening, plyometric exercises and balance appear to be key to IPPs designed to reduce knee injury (Baldon Rde, Serrão, Scattone Silva, & Piva, 2014; Waldén, Atroshi, Magnusson, Wagner, & Hägglund, 2012). The presence of exercises that engage hip muscles (eg, gluteal muscles) and ACL agonist knee muscles (eg, calf and hamstrings), are thought to contribute to improved knee alignment during landing (Petushek, Sugimoto, Stoolmiller, Smith, & Myer, 2019). Furthermore, improving general lower extremity muscle strength through neuromuscular training (NMT), has been shown to improve biomechanical landing ability and improve jumping performance (Barber-Westin, Noyes, & Galloway, 2006; Herrington, 2010; Hewett, Ford, & Myer, 2006). Strengthening components and landing technique correction may also decrease GRF by improving absorption through the musculoskeletal structures (Myer et al., 2009). Safe repeated landing can also specifically help young adolescent females reach peak bone mass, preventing osteoporosis and associated fractures in adulthood, without danger to growing joints (Rebai et al., 2012). An IPP that develops proper motor control prior to and throughout maturation is also beneficial to counteract the rapidly changing physical, hormonal and neurological changes occurring during the adolescent growth spurt (Root et al., 2015).

A netball IPP should therefore integrate many of the above exercise components, including strength and plyometric movements that improve hip and ACL agonist muscles and landing technique motions (Fox, Spittle, Otago, & Saunders, 2014; Myer et al., 2009). The IPP should also contain some integrated trunk-lower extremity neuromuscular control exercises, which replicate the challenges of catching a netball in varied aerial and unbalanced positions to successfully replicate game demands (Nyland, Burden, Krupp, & Caborn, 2011; Zazulak et al., 2007). Finally, a component of balance training for preventing ankle sprains should still make-up some part of a netball IPP, considering ankle sprain continues to represent the most common netball injury (de Villiers & Venter, 2014; Langeveld et al., 2012).

Several recent narrative and systematic reviews on IPPs have clearly shown that a variety of successful NMT and warm-up interventions utilise similar exercise components and are comparable in suggested exercise dosage, number of sessions per week and length of programme (Emery, Roy, Whittaker, Nettel-Aguirre, & van Mechelen, 2015; Hadzovic et al., 2020; Michaelidis & Koumantakis, 2014; Sommerfield, Harrison, Whatman, & Maulder, 2020). The similarities found amongst these mixed methods IPPs (NMT or warm-up), suggest that perhaps an IPP does not necessarily need to come in any one format or even be purely sports-specific (Mugele et al., 2018). The majority of studies term their IPPs as sports specific (Junge et al., 2011; Soligard et al., 2010; Sugimoto, Myer, Foss, & Hewett, 2014) when they actually include components that develop general physical abilities, e.g., balance, core stability or power. Perhaps the key is to use a wide array of exercises that pertain to both sports-specific and general movements (Mugele et al., 2018), whilst allowing for adaption to suit differing maturation changes, skill-level and genders (Faude et al., 2017; Sommerfield et al., 2020). What this research does suggest is that adaptation or modifications to existing IPPs may not reduce their effectiveness at reducing injury risk or increasing performance if the foundation common injury-prevention exercises remain (Faude et al., 2017; Hadzovic et al., 2020; Mugele et al., 2018).

Facilitation and barriers to IPP implementation

Randomised control studies (RCTs) have clearly demonstrated evidence-based efficacy of IPPs and their initial implementation (Emery et al., 2015; Mehl et al., 2018; Sugimoto et al., 2014), however barriers remain to the enduring success of these programmes. One of the suggested obstacles to implementation is a 'research to practice' gap. Specifically, the RCTs do not accurately reflect the real-world sport context in which the intervention is to be implemented (Donaldson & Finch, 2013; Hanson, Finch, Allegrante, & Sleet, 2012). The high levels of efficacy reported in RCTs often require the IPP be led by health or exercise science professionals (Impellizzeri et al., 2013; McKenzie, Whatman, Brughelli, & Borotkanics, 2019; Steffen et al., 2013). It is unrealistic to expect a school or club at community level to rely on physiotherapists or strength and conditioning coaches to supervise warm-up routines. As a result, these programmes are simply not widely adopted or sustained in regular training practices, restricting their impact (Ageberg, Bunke, Lucander, Nilsen, & Donaldson, 2019; Finch, 2006). The effectiveness of warm-up IPPs may therefore be better evaluated when coach-led/physical educator-led within community-level training environments, which will add ecological validity to the research (Gianotti, Hume, & Tunstall, 2010; Pfile & Curioz, 2017; Richmond et al., 2020; Steffen et al., 2013). A good example of this is (Emery et al., 2020), who reduced sports injuries by successfully implementing an injury prevention NMT programme called (iSPRINT) amongst six junior high schools (22 classes) of students, led by the school physical education personnel.

Another important aspect to the success of an IPP at reducing injury risk, other than choosing the most relevant exercise content is high levels of compliance to the program (Sugimoto et al., 2017). Several studies of IPPs have indicated reductions in injury around 35-88%, if players remain compliant (Bogardus, Martin, Richman, & Kulas, 2019; Soligard et al., 2010; Sugimoto et al., 2017). Potential barriers for non-compliance include: lengthy warm-up time, poor relevance to the sport, reduced space to perform warm-up, too many sets/reps for young players and boredom (O'Brien, Young, & Finch, 2017b). Current research suggests poor adherence/compliance remains a problem. Saunders et al. (2010), showed that 88% of coaches believed a specific netball IPP could improve landing technique and 71% found them effective at reducing injury. Nevertheless, only approximately 50% adhered to the program, citing barriers such as lengthy warm-up time, no relevance to the sport, decreased space to perform warm-up, too many sets/reps for young players and boredom (O'Brien et al., 2017b; Saunders et al., 2010). In response to these suggested barriers, NetballSmart adapted the existing NSDW to create a separate shorter PWU (Appendix III). The PWU removed some running, core and Nordic hamstring strengthening exercises, whilst retaining many of the plyometric jump/landing, squat and single-leg movements.

The coach's role is important to successful implementation of an IPP warm-up, as they must motivate their players to stick-with the program and teach them correct technique (Saunders et al., 2010; White et al., 2014). To improve the coach's ability to effectively implement a new warm-up, they require adequate access to recent resource tools and appropriate knowledge/education on why the exercise movements are essential to the game (Martinez et al., 2017; White et al., 2014). Though the primary aim of the NSDW and PWU was to reduce netball injuries, improved physical performance was also a desired outcome. The belief was that performance enhancement would act as motivation for compliance and acceptance(Saunders et al., 2010; White et al., 2012). Club managers and coaches remain important stakeholders in the distribution and successful implementation of national warm-up IPPs, but often it is difficult to positively affect uptake based solely on injury prevention (Finch, 2006; White et al., 2012; Zarei et al., 2018). If a positive effect on players' performance or increased emphasis on player availability due to reduced injury was offered as outcomes of an IPP, acceptance may be higher (Saunders et al., 2010; Steffen, Bakka, Myklebust, & Bahr, 2008; Zarei et al., 2018). It would therefore seem ideal to show an IPP warm-up not only reduces injury but also improves player performance.

To date there are very few studies investigating injury prevention in female netball players and no evidence for the effectiveness of NSDW specifically for improving landing technique. Recent research has shown the NSDW can benefit performance (prone hold, balance and vertical jump) in 13-15-year-old netball players (McKenzie et al., 2019). Another age group (15-19-year-olds) that constitute a high proportion of national netball participants, should also be the focus of further research into the effects of the NSDW on physical performance measures. Similarly, with the creation of the new PWU, it is essential to explore the effectiveness of the original NSDW compared to this new adaptation on physical performance and landing ability. Recognising which outcomes these NNZ warm-ups can improve the most, will help direct education in their use for netball players, coaches, parents and medical support staff throughout the season.

Recently several studies have focused on establishing models and frameworks for successful IPP implementation and adoption (Donaldson & Finch, 2013; O'Brien & Finch, 2014). Several frameworks have been suggested for successful implementation of IPPs including Translating Research into Injury Prevention Practice (TRIPP) (Finch, 2006), Reach Efficacy Adoption Implementation Maintenance (RE-AIM) (Gaglio, Shoup, & Glasgow, 2013), Implementing Injury Preventive Training (IIPT) (Padua et al., 2014) and Theory of Planned Behaviour (TPB) (Chung Chan, Yeung Lee, Hagger, Mok, & Yung, 2017). These studies have helped identify realistic and practical cyclic steps that can be followed for the development and evaluation of IPPs, but do not necessarily recognise the individual barriers or facilitators to implementing a successful programme in a real-world sporting context.

One of the first steps in successfully implementing an IPP, especially on a national level, is to identify the key stakeholders driving creation, dissemination, delivery, maintenance, and outcomes of programmes (Ageberg et al., 2019; Donaldson et al., 2016). The TRIPP model theorizes sport bodies will be unwilling to implement sport safety policies until they are accepted by the coaches and athletes (Finch, 2006). Research has begun to identify the different barriers and facilitating factors that hold most prominence amongst individual stakeholder groups, including coaches (Norcross, Johnson, Bovbjerg, Koester, & Hoffman, 2016; Saunders et al., 2010), players (Martinez et al., 2017; White et al., 2012) and organisational leads (Dahlström, Jacobsson, & Timpka, 2015; DiStefano, Frank, Root, & Padua, 2017). Evidence would suggest that these stakeholders may have differing needs from IPPs. For example, organisation administrators may place more importance on team success in league tables or availability of players. In contrast end users (players) are more concerned with personal reduction in injury risk and that the IPP fits within their training time (Finch et al., 2014; Martinez et al., 2017; Norcross et al., 2016). What is clear is that if stakeholders fail to recognise a positive cost-benefit of a programme, their support and motivation to deliver this to their sporting population will be poor (Ageberg et al., 2019; Donaldson et al., 2016; Richmond et al., 2020). There is a real need for further research investigating why individuals and organisation do, or do not adopt an IPP (Ageberg et al., 2019; Richmond et al., 2020).

Recognition of the effects of internal barriers (self-efficacy, values of the programme, motivation to engage) on player and coach motivation to disseminate an IPP, is not the only area of implementation that needs investigation. Awareness of external barriers (program content, media, role models, support and knowledge) to successful IPP acceptance is also critical (O'Brien, Young, & Finch, 2017a; Richmond et al., 2020). Interpretating how to overcome these barriers with practical solutions can facilitate adoption and sustained fidelity of IPPs (Ageberg et al., 2019). Creating an IPP implementation plan like that of TRIPP which has several cyclic practical steps for implementation and evaluation, but which considers all the above barriers, is an essential process in gaining programme success.

Purpose of the Thesis

The overall aim of this thesis was to improve the design and implementation of New Zealand’s NetballSmart, IPP.

The specific objectives of this thesis were to:

1. Review the evidence for barriers and facilitators in IPP implementation and identify practical solutions that can facilitate adoption and sustained effectiveness.

2. Review netball ankle and knee injuries in New Zealand over a 10-year period, with a focus on seasonal changes and age group differences.

3. Analyse the mechanism of ACL injury from game play video clips, with an emphasis on the effect of player behavioural patterns and how this information can be translated into coachable injury prevention messages.

4. Explore the effectiveness of two netball specific warm-up programmes (NSDW and PWU), on improving physical performance and landing ability.

5. Discuss how the research findings from the chapters within the thesis have been practically applied within the NIPP.

Significance of the Research

Many previous IPPs have failed to maintain their efficacy after their initial release. This can be for a variety of reasons including inappropriate design and poor implementation planning. Another issue raised in the literature is a ‘research-to-practice gap’, where the evidence-based IPP content fails to reach the correct audience or meet the needs and values of the key stakeholders of the programme. Previous research has shown that for those implementing an IPP to be confident in its effectiveness it must be developed from recent research and designed for the specific needs of the audience it is being driven towards. An IPP targeting a specific sport should offer adequate access to recent resource tools and appropriate knowledge/education on why the programme content meets the physical demands of the game. Therefore, this research sort to improve the design and successful implementation of a national IPP. This was achieved through obtaining evidence of injury patterns and mechanisms that then informed ongoing design and delivery of the NIPP. The thesis also, evaluates a neuromuscular warm-up specifically adapted to address several of the proposed barriers to real-world implementation. Finally, comment is made on how the evidence presented in the thesis has been translated into practical recommendations that guide the implementation strategy, resource development and educational workshop content, within the national NIPP.

Structure of the Thesis

This thesis is comprised of Eight Chapters, (See Figure 1. Thesis flow chart). The flow of the thesis narrative broadly follows the four stages of the van Mechlen, Hlobil, & Kemper (1992), “sequence of prevention stages” injury prevention model. **Chapter two** is a narrative review evaluating existing evidence for facilitating factors and barriers to implementing IPPs/neuromuscular warm-up programmes. **Chapter three** then describes the epidemiology of netball knee and ankle injuries from 10-years of ACC injury records. Both these chapters help guide the implementation plan for the NIPP, as well as directing the content of the programme’s educational resources and workshops to best meet the needs of the target audience. **Chapter four** analysed the mechanism of ACL injury (a significant concern in netball) from game play video clips, with an emphasis on the effect of player behavioural patterns and how this information could be translated into coachable injury prevention messages. **Chapters five & six** explored the effectiveness of two differing lengths of existing NIPP netball specific neuromuscular warm-up programmes (NSDW and PWU) on improving physical performance and landing ability in youth netballers. The results from chapter 3 informed the target age group recruited for this study and the coaching educational workshops provided as part of the implementation for both warm-ups were further guided by the results from *chapter four*. **Chapter seven** provides a commentary on how the research from the chapters within the thesis, has been applied within the real-world NIPP setting thus far and how this has impacted the programme.

The chapters in this thesis were written in the format of the respective journal to which they were submitted, except in the case of the first and eighth. A preface explaining how each chapter is linked in the larger narrative of the thesis, has been written into the beginning of *Chapters two-to-seven*. Due to the nature of the thesis structure (pathway two, thesis by publication), there may be some repetition between thesis chapters.

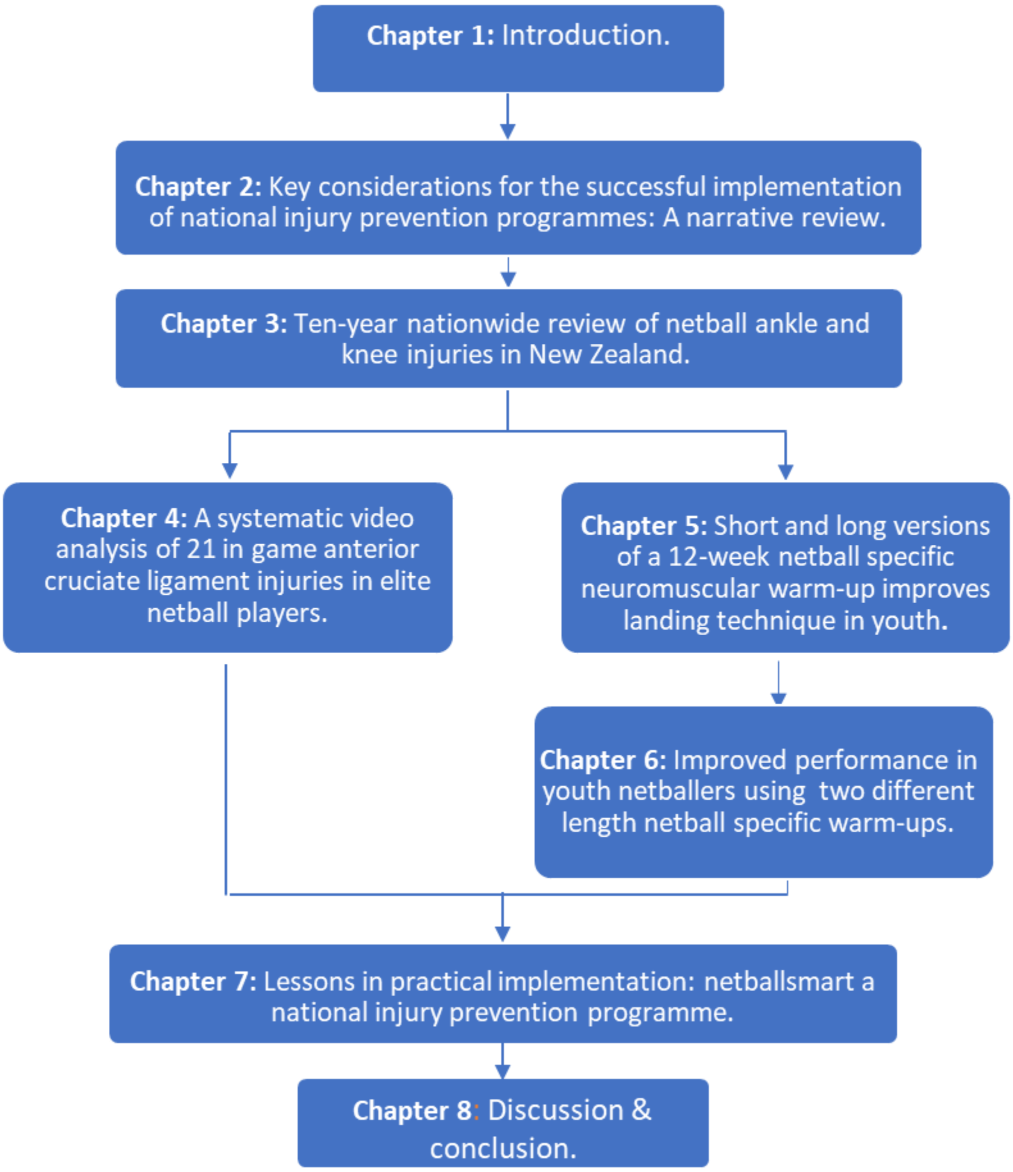


Figure 1. Thesis chapter flow chart.

CHAPTER TWO: KEY CONSIDERATIONS FOR THE SUCCESSFUL IMPLEMENTATION OF NATIONAL INJURY PREVENTION PROGRAMMES: A NARRATIVE REVIEW

Prelude

Many national IPP fail to gain greater adoption not because the exercise or informative content of their programmes lacks empirical validation, but because no strategic implementation plan was designed and followed. The implementation process can fail due to a variety of external barriers and internal barriers. With this in mind the first step to improve the implementation and design of the NIPP was to explore the literature to identify how to overcome these barriers with practical solutions that could facilitate adoption and sustained fidelity of an IPP. A narrative review was utilised to allow for a broader interpretation and exploration of the current evidence, rather than a systematic review with a more narrowly defined study question that may have excluded relevant studies. A second aim was to create a practical and strategic implementation process the programme could utilize throughout its first three-years of funding. This process would need to be cyclic in nature, so as regular evaluation of programme feasibility and adoption could be incorporated. Thus, allowing for targeted programme resource and educational workshop development annually.

This chapter comprises the following paper published in New Zealand Journal of Sports Medicine:

Belcher, S., Whatman, C., & Brughelli, M. (2021). Key considerations for the successful implementation of national injury prevention programmes: A narrative review. *New Zealand Journal of Sports Medicine*. (In Press).

Abstract

Aim: This narrative review: a) evaluates evidence regarding the implementation of sports injury prevention programmes (IPPs), identifying barriers and facilitators to implementation and key stakeholders and b) proposes practical guidelines to improve the implementation of national IPPs.

Data sources: Databases accessed: (a) Science Direct, (b) PubMed, (c) Embase, (d) Sport Discus, and (e) Scopus. Online search expression used various combinations of the terms ‘‘Injury Prevention Programme/s; Success/Barriers; Perspective/s; Implementation”.

*Study selection**:*** Inclusion criteria: (a) from peer-reviewed journals, (b) full text available in English, (c) study or systematic review discussed the implementation of sports injury prevention programmes, and/or discussed attitudes/behaviours/beliefs of those performing sports injury prevention programmes.

Data extraction: The 35 studies extracted were reviewed to identify any consistent themes/key considerations that pertain to improving successful implementation of an IPP. These themes were then further sub-divided into associated topics.

Findings: Themes and sub-divisions: **The importance of stakeholders-** Players/end-users, Coaches, Sports organisation personnel, Other stake holders; **The importance of collaboration-** Shared ownership of the programme, Shared responsibility for programme evaluation; **Relevant content-** Evidence based, Recognisable, Adaptable, Overcoming logistical barriers; **Implementation-** Education, professional development and support, Resource development, Ambassadors and role models, Social media and promotional plans.

Conclusions: There is evidence of common facilitators and barriers that need to be considered when implementing IPP's. The practical guidelines we propose should enhance the implementation of IPP's in real world settings. **Step 1:** Form a multi-disciplinary collaborative IPP design group containing all key stakeholders and research personnel. **Step 2:** Undertake and review empirical research gathered from a range of research areas/fields. **Step 3:** Develop programme resources in a variety of formats, including video, website, infographics, workshop booklets. **Step 4:** Design a dissemination plan, focusing on promotional advertising through social media, television adverts and written releases. **Step 5:** Offer support systems for stakeholders to give feedback on IPP performance and adaptations to better suit their teams needs and values. **Step 6:** Test the feasibility and adoption of the programme, whilst gathering feedback from community on the IPP effectiveness.

Key words: Injury prevention, Programme implementation, Barriers, Facilitators, Translation

Introduction

Sport remains one of the major causes of injury and lower extremity acute and overuse injuries in ball sports, such as team handball, football, basketball, rugby and netball are particularly common and costly (Åman, Forssblad, & Larsén, 2018; Belcher, Whatman, Brughelli, & Borotkanics, 2020; King et al., 2019). Injury prevention programmes (IPPs) are thus essential to minimise the associated treatment costs, participation loss and long-term negative effects of injury (Donaldson et al., 2016; Fulcher et al., 2018; Kuijt, Inklaar, Gouttebarge, & Frings-Dresen, 2012). IPPs and neuromuscular warm-up, in particular, have shown considerable promise for reducing injury risk in several sports (Myklebust, Skjølberg, & Bahr, 2013; Steffen et al., 2013). There is good evidence a neuromuscular warm up can reduce injury by approximately 50%, when performed at least twice weekly, when exercise technique is of consistently good quality and the programme design specific to the sport (Emery et al., 2015; Saunders et al., 2010; Soligard et al., 2010). However, evidence also suggests that achieving adequate compliance to prevention programmes continues to be challenging and this is limiting real-world effectiveness (Soligard et al., 2010; Steffen et al., 2013). Identifying the specific implementation components that influence the adoption, execution and maintenance of IPP interventions or act as barriers to their acceptance is essential to improved success (Dahlström et al., 2015; Donaldson & Finch, 2013; O'Brien & Finch, 2014).

The majority of injury prevention research has largely focused on determining which programme components have the greatest effect on reducing injury or improving performance and the subsequent dosage requirements (Emery et al., 2015; Sugimoto et al., 2014). These randomised control studies (RCTs) have been essential to the creation of the content of modern sport IPPs. However, even with a clear demonstration of evidence-based effectiveness in the initial implementation phases of these IPPs or through RCT studies, there remains barriers to maintained success of these programmes in the real-world setting. It has been suggested that one of the key obstacles to implementation, is a 'research to practice' gap, as the RCTs do not accurately reflect the real-world sport context in which the intervention is hoping to be implemented (Donaldson & Finch, 2013; Hanson, Allegrante, Sleet, & Finch, 2014). Beyond the research setting, these programmes are simply not widely adopted or sustained in regular training routines, thus, restricting their impact (Ageberg et al., 2019; Donaldson & Finch, 2013).

Recently there has been an increase in the number of studies focused on establishing models and frameworks for successful IPP implementation (Donaldson & Finch, 2013; O'Brien & Finch, 2014). Many frameworks have been suggested for successful implementation including; Translating Research into Injury Prevention Practice (TRIPP) (Finch, 2006) , Reach Efficacy Adoption implementation Maintenance (RE-AIM) (Gaglio et al., 2013), Implementing Injury Preventive Training (IIPT) (Padua et al., 2014; van Mechelen, 1997) and Theory of Planned Behaviour (TPB) (Chung Chan et al., 2017), to name a few. Studies based on these frameworks have helped identify realistic and practical steps useful in the development and evaluation of IPPs, but do not necessarily recognise the individual barriers or facilitators to implementing a successful programme in a real-world sporting context. Of the commonly followed models, TRIPP appears to be best designed for achieving real-world buy-in from its target community (Finch, 2006; Tiggelen, Wickes, Stevens, Roosen, & Witvrouw, 2013). The focus on real-world contextual implementation, evaluation and analysis of programme outcomes added by Finch (2006) to van Mechelen's (1997) original model, recognises the necessity to understand key stakeholders needs for programme engagement (Ageberg et al., 2019; O'Brien & Finch, 2013; Tiggelen et al., 2013). Although this model identifies the importance of an implementation strategy for IPP dissemination, it fails to offer any specific practical guidelines or strategies on how to achieve this implementation process. It is these real-world practical strategies that clinicians, sporting personnel or organisations require to affectively role out an IPP.

Key to successful implementation is understanding why individuals and organisations do, or do not adhere to an IPP (Ageberg et al., 2019; Richmond et al., 2020). Several studies have focused on identifying the key stakeholders driving IPP creation, dissemination, delivery, maintenance, and outcomes. Research has explored the attitudes and behaviours of different stakeholders implementing an IPP (coaches (Norcross et al., 2016; Saunders et al., 2010), players (Martinez et al., 2017; White et al., 2012), organisational leads (Dahlström et al., 2015; DiStefano et al., 2017)) and their interpretation of what enables or obstructs optimum delivery. If stakeholders fail to recognise a positive cost-benefit of a programme, their support and motivation to deliver this to their sporting population will be reduced (Ageberg et al., 2019; Donaldson & Finch, 2013; Richmond et al., 2020). The lack of stakeholder motivation however is not the only barrier to implementation of an IPP. Recognition of the effects of external barriers (programme content, media, role models, support and knowledge) or internal barriers (self-efficacy, values of the programme, motivation to engage) to the successful uptake is also vital (O'Brien & Finch, 2014; Richmond et al., 2020). Understanding how to overcome these barriers with practical solutions can facilitate adoption and sustained fidelity of injury prevention programmes in the future (Ageberg et al., 2019; Finch et al., 2014).

Thus, the aim of this narrative review was to evaluates evidence regarding the implementation of sports IPPs, identifying barriers and facilitators to implementation and key stakeholders We also propose practical guidelines for the successful implementation and dissemination of national IPPs in real world settings.

Method Search Strategy

This is a narrative review with a systematic search strategy as described below:

Data Sources

The online search expression used to locate published studies for this review used various combinations of the terms ‘‘Injury Prevention Programme/s; Success/Barriers; Perspective/s; Implementation”.

Study Selection

Five online databases were accessed: (a) Science Direct, (b) PubMed, (c) Embase, (d) Sport Discus, and (e) Scopus. Articles were limited to those published between 2000 and 2020. In addition, a snowballing literature search method was performed, by identifying relevant references within the reference lists of previously selected studies (Gasparyan, Ayvazyan, Blackmore, & Kitas, 2011).

Inclusion criteria for articles in this literature search were as follows: (a) from peer-reviewed journals, (b) full text available in English, (c) study or systematic reviews discussed the implementation of sports injury prevention programmes, and/or discussed attitudes/behaviours/beliefs of those performing sports injury prevention programmes.

Data Extraction

A narrative review was utilised to allow for a broader interpretation and exploration of the current evidence (Greenhalgh, Thorne & Malterud, 2018). We recognise the benefits of a systematic review regarding the potential to reduce selection bias, however the stricter boundaries of the search criteria created by a narrowly defined study question can often lead to important interpretations of a study's findings being missed or rejection of relevant studies (Greenhalgh, Thorne & Malterud, 2018).

Findings

Thirty-five studies that meet the inclusion criteria were identified and reviewed for themes pertaining to improving the successful implementation of an IPP, with particular emphasis on national scale dissemination. For each theme discussed below we have included in brackets the number of studies (n) that provided evidence in support of the theme.

Visual inspection of **Table 1.** shows an overview of the design of the 35 identified studies and clearly shows most studies pertain to community/recreational level players. Only two studies focused on elite athletes and a further two studies discussed both community and elite level players. Most studies explored findings from a variety of sports (mainly team based) and utilised qualitative methodologies, rather than quantitative. The targeted population for a national IPP will mostly consist of recreational/community-level players, whilst still accounting for some elite-level members. The literature reviewed within this study reflects this and largely discusses barriers and facilitations to IPPs at a recreational/community-level with only occasional reference to high-performance.

The importance of key stakeholders (n =23)

Recent research exploring the dissemination of IPPs has highlighted the importance of identifying key stakeholders of a programme and how best to reach them (Donaldson & Finch, 2013; O'Brien & Finch, 2014; Richmond et al., 2020). The content and messages of an IPP must be compatible with the needs and values of all key stakeholders and influencers (Morgan, Johnson, Bovbjerg, & Norcross, 2017; Rogers, 2002). Key stakeholders are more likely to utilise the programme if they believe the intervention addresses an important issue for their teams/players/children and if they were consulted in the design process (McKay, Steffen, Romiti, Finch, & Emery, 2014; Morgan et al., 2017; Norcross et al., 2016).

Players/end-users

One of the acknowledged stakeholders is the players themselves, as they are the main health beneficiaries of the programme (Ageberg et al., 2019; Lindblom, Carlfjord, & Hägglund, 2018). The players opinion can often be lost during the creation and distribution of an IPP. However, it is their compliance to the programme, along with the subsequent reduction in injury that remains the measure of success of any IPP. Evidence supports an inverse dose response relationship between compliance with an IPP and injury risk, higher rates of compliance lead to greater decreases in risk of injury (Hägglund, Atroshi, Wagner, & Waldén, 2013; Soligard et al., 2010). Players are generally willing to carry-out an IPP if it can be performed within a normal training environment or game and if it is adaptable to reduce boredom, progressive and more specific to game demands (Martinez et al., 2017; O'Brien & Finch, 2014).

Players appear to collectively agree that it is the responsibility of the coach or support staff (Physiotherapist) to guide them in the initial design and delivery of an IPP (Lindblom et al., 2018; White et al., 2012). However, some players have identified that an opportunity to lead the warm-up would improve their motivation to adhere to the content and give them a feeling of ownership or control (Gokeler, Benjaminse, Seil, Kerkhoffs, & Verhagen, 2018; O'Brien & Finch, 2014; Saunders et al., 2010). Initial design and guidance by the coaches on IPP performance is crucial, but with an option to challenge players to run the IPP themselves once they are comfortable to do so. Of all stakeholder groups, players put the most emphasis on using 'role models' within the sport and social media to sell the positive messages of the programme (Ageberg et al., 2019; Lindblom et al., 2018; White et al., 2012). Finally, differences between genders have been identified. Males appear to be motivated by potential performance benefits from an IPP and females by its success at reducing injury risk (Finch et al., 2014; Hägglund et al.2013; Waldén, et al., 2013). Modifying how you sell the IPP benefits and use of gender specific messaging, may therefore be beneficial.

Table 1. Overview of study designs

Study	Sport	No. Participants or studies	Study method	Community or elite level
Ageberg et el., 2018	Handball	196	Concept mapping	Community
Bekker et al., 2017	AF	6	Interviews	Community
Bizzini & Dvorak, 2013	Soccer	N/A	Commentary	Community
Brown et al., 2014	Rugby	N/A	Commentary	Community
Brown et al., 2016	Rugby	3921	Questionnaire	Community
Bruder et al., 2019	Soccer	27	Survey	Elite
Dahlström et al., 2015	Athletics	32	Focus group	Both
Distefano et al., 2017	Mixed	12 studies	Systematic review	Community
Donaldson & Finch, 2013	Mixed	N/A	Commentary	Community
Donaldson et al., 2016a	AF	7	Intervention mapping	Community
Donaldson et al., 2016b	AF	4	Intervention mapping	Community
Donaldson et al., 2018	Soccer	64	Survey	Community
Finch, 2006	Mixed	N/A	Commentary	Community
Finch et al., 2013	Soccer	442	Survey	Community
Frank et al., 2015	Soccer	34	Survey	Elite
Fulcher et al., 2018	Soccer	N/A	Commentary	Community
Gaglio et al., 2013	Health based	71	Systematic review	Community
Goekeler et al., 2018	Mixed	N/A	Commentary	Community
Hanson et al., 2012	Mixed	N/A	Commentary	Community
Joy et al., 2013	Soccer	756	Report form	Community
Lindblom et al., 2017	Soccer	20	Interview	Community
Martinez et al., 2016	Mixed	76	Survey	Community
McGlashan et al., 2018	AF	2	Interviews	Community
McKay et al., 2014	Soccer	287	Questionnaire	Community
Morgan et al., 2018	Soccer	54	Survey	Community
Myklebust et al., 2013	Handball	N/A	Commentary	Community
Norcross et al., 2013	Mixed	141	Survey	Community
O'Brien & Finch, 2014	Mixed	60 studies	Systematic review	Both
Padua et al., 2014	Mixed	N/A	Commentary	Community
Poulos & Donaldson, 2012	Rugby	70	Questionnaire	Community
Richmond et al., 2020	Mixed	47	Focus group	Community
Saunders et al., 2010	Netball	31	Survey	Community
Steffen et al., 2012	Soccer	385	Report Form	Community
Sugimoto et al., 2012	Mixed	6 Studies	Meta-analysis	Community
White et al., 2012	Netball	287	Questionnaire	Community

AF= Australian Football

Coaches

The majority of studies exploring IPP implementation focus on coaches being uniquely placed in a position of trust/respect to guide players through the programme and integrate them within the sport (Lindblom et al., 2018; Lohmander, Englund, Dahl, & Roos, 2007; McGlashan, Verrinder, & Verhagen, 2018; Norcross et al., 2016). Coaches often cite barriers/facilitators to IPP implementation success that are like those cited by players. Coaches are often motivated to execute an IPP if they understand the science behind exercise content choice and evidence of programme success (Ageberg et al., 2019; Brown, Gardner-Lubbe, Lambert, van Mechelen, & Verhagen, 2018; McGlashan et al., 2018). This group of stakeholders regularly identified that injury prevention alone was not always enough of a motive to utilise a programme and improved player performance was essential, especially in males (Joy et al., 2013; Lindblom et al., 2018; McGlashan et al., 2018). Conversely, coaches of female teams are more likely to utilise an IPP than those of male teams in general, as they believe they are at greater risk of injury and it is therefore of greater value (Morgan et al., 2017; Norcross et al., 2016). Coaches and other stakeholders often choose not to use an IPP programme as they do not believe or understand that their team is at risk (Bekker & Clark, 2016; Dahlström et al., 2015; McGlashan et al., 2018). Coaches often believe that their players are unwilling to perform an IPP as they do not feel they are at risk (Martinez et al., 2017; Norcross et al., 2016). Though, research would indicate that the opposite is true, and players are often motivated to undertake an IPP, as they believe it will reduce their risk of injury (Martinez et al., 2017; McKay et al., 2014). Clearly there has been a miss communication between player and coach. Evidently there is a need to bridge the research to real-world practice gap, where the interpretation of the evidence can be better translated to ensure understanding of the key stakeholders. A strategy to achieve this is through education workshops on the programmes ability to benefit health, wellbeing and sporting performance (Finch et al., 2014; Saunders et al., 2010; Steffen et al., 2013).

An identified apprehension amongst coaches is a need for support and feedback from healthcare/exercise science professionals, coaching peers and the sport organization they work with (McGlashan et al., 2018; Richmond et al., 2020; Saunders et al., 2010; White et al., 2012). Coaches want a structured support system to confidently implement an IPP (McGlashan et al., 2018), some of which they feel should come directly from the organisation they work with, whether at a national or club level (O'Brien & Finch, 2014; Richmond et al., 2020).

Sports organisation personnel

One of the key stakeholders often overlooked in IPP implementation research is the sport organization itself. Recent studies theorising IPP implementation best practice have highlighted the growing importance of merging sports organisations at all levels. Organisation administrators often act as the initial instigators of a community IPP, as they will develop policies to help dissemination, secure economic backing for coaching professional development and publicising/branding the programme (Dahlström et al., 2015; Donaldson et al., 2016; Frank, Register-Mihalik, & Padua, 2015; Richmond et al., 2020). Like coaches a key reason organization’s sponsor the dissemination of an IPP is clear scientific evidence of reduced injury rates, increased team success and increased availability of players (Dahlström et al., 2015; Norcross et al., 2016; O'Brien & Finch, 2014; Richmond et al., 2020). Unlike other stakeholders’ organisations are often responsible for the cost of an IPP, whether financing workshops for coaches or funding media outlets to promote the programme (Dahlström et al., 2015; Frank et al., 2015; Fulcher et al., 2018; Richmond et al., 2020). The organisation must be convinced the benefits of running the programme, outweigh the costs (Lindblom et al., 2018; McGlashan et al., 2018; Rosenstock, Strecher, & Becker, 1988). The organization plays an important part in the greater sporting community receiving information about an IPP and building confidence through endorsement of the programme amongst differing social groups (Ageberg et al., 2019; Frank et al., 2015; Fulcher et al., 2018; Richmond et al., 2020).

Other stakeholders

There are other stakeholders in implementation, who play a greater or lesser role depending on the audience of the IPP or environment of its delivery. Physical education teachers for instance play a similar role as the coach in some IPPs (Frank et al., 2015; Richmond et al., 2020). Parents may play a key role in encouraging players to undertake an IPP, either from a guardian standpoint or as a volunteer coach (O'Brien & Finch, 2014; Richmond et al., 2020). Research however has shown that some coaches and parents do not believe that younger players are at real risk of injury and that an IPP need not be a focus of youth sport training (Morgan et al., 2017; Richmond et al., 2020). However, there is strong evidence that youth players are at risk not only of initial injury, but potentially long-term effects to their physiological and psychosocial wellbeing (Belcher et al., 2020; Joy et al., 2013; Lohmander et al., 2007). Healthcare and exercise science professionals often guide coaches through IPP education or lead the programme for teams, as it builds confidence in the quality of programme delivery (Ageberg et al., 2019; Brown et al., 2018; Saunders et al., 2010). The beliefs or attitudes of these key professional influencers (e.g., Physiotherapists or Strength & Conditioning coaches) on implementation of IPP are rarely if ever discussed within the literature and this remains an important area of future research. Recent research into the above-mentioned stakeholders’ values, has identified a growing appreciation for content that recognises the importance of end-user’s general health, wellbeing and cultural needs (Ageberg et al., 2019; Dahlström et al., 2015; Myklebust et al., 2013). Ultimately for an IPP to reach its dissemination potential it must consider the diverse values and needs of the key stakeholders when developing its content and promotion, to better target their audiences.

The importance of collaboration (n = 16)

Shared ownership of the programme

A frequently cited barrier to implementation, is the lack of perceived control key stakeholders feel they have over the programme (Ageberg et al., 2019; Dahlström et al., 2015; McGlashan et al., 2018; Padua et al., 2014). Stakeholders at all levels (organisational, implementer and user), often believe they have been given little or no opportunity to participate in programme design, dissemination and implementation (Ageberg et al., 2019; DiStefano et al., 2017; O'Brien & Finch, 2014). To 'bridge the gap' between research and practical application of IPPs, a 'real-world' perspective gained from all key stakeholders is essential. Organizations are more likely to support an IPP if they have collaborated with the research team in extrapolating what they see as real-world practical implications from the evidence presented to them (Ageberg et al., 2019; Fulcher et al., 2018; Richmond et al., 2020). They can use the evidence to guide their policies and integrate the IPP throughout all levels of their organisation, reaching a larger number of end users (Ageberg et al., 2019; Donaldson, Lloyd, Gabbe, Cook, & Finch, 2017; O'Brien & Finch, 2014). Organizations support dissemination by many means, such as making a programme mandatory, promoting its benefits and encouraging and funding educational workshops. Undoubtedly a programme that is endorsed and advertised as successful by a national sporting organisation, will garner greater trust and reception by the end-users. Similarly, at a centre or club if time is placed into the competition draw for an IPP (e.g., a warm-up) to be performed, it is more likely to be utilised and followed by the community.

Though collaboration with those developing organisational policy can be beneficial to dissemination of an IPP, the influence of these stakeholders alone may be insufficient for continued successful acceptance of the programme (Donaldson et al., 2016; Frank et al., 2015; Hanson et al., 2012). Probably the most important collaboration is between the researchers, implementors (Coaches, teachers, parents) and end-users (players). Implementors and end-users often suggest innovative ways to overcome logistical barriers and offer new perspectives on the programme content (Bekker, Paliadelis, & Finch, 2017; Donaldson et al., 2017). These collaborations offer a chance for implementors/end-users to give honest advice on which exercises will realistically fit into the team training environment and whether the content descriptive language is easily understandable. It is apparent that an IPP must be empirically researched and influenced to be widely accepted by key influencers at all levels of a sport (Ageberg et al., 2019; Donaldson et al., 2016; McGlashan et al., 2018; Norcross et al., 2016; O'Brien & Finch, 2014). Notably key influencers have more confidence, in an IPP if the research was compiled by a multidisciplinary group, particularly through collaboration with the end-user and the organisational policymakers (Ageberg et al., 2019; Bruder et al., 2020; O'Brien & Finch, 2014; Padua et al., 2014).

Shared responsibility for programme evaluation

For a programme to be sustainable and therefore effective partnership with stakeholders must reach beyond just the initial planning and propagation of an IPP, it must be maintained throughout (Dahlström et al., 2015; Frank et al., 2015; Padua et al., 2014). The use of focus groups, large informal discussion meetings and questionnaires amongst stakeholders to provide feedback on IPP outcomes is valuable to programme improvement and maintaining its acceptance within the community (Bruder et al., 2020; McGlashan et al., 2018; Padua et al., 2014). Collaborating with a variety of personnel to evaluate IPP outcomes (injury databases, player compliance etc), is essential to building programme maintenance and development strategies (Donaldson et al., 2017; O'Brien & Finch, 2014; Padua et al., 2014). Collaboration with key stakeholders therefore likely improves programme quality and their perceived control over its application, which in turn increases their acceptance and motivation to disseminate the IPP further.

Relevant content (n = 23)

Evidence based.

IPPs are more commonly accepted if the evidence has been recently gathered from a range of research areas/fields (Cadaveric, Computational models, Video analysis, efficacy/effectiveness and laboratory studies) or through a research clinic (Finch et al., 2014; Richmond et al., 2020). Recent research has indicated that coaches and players desire clear visual data and statistics on IPP effectiveness to have confidence in supporting its use with their own team or promoting it to others (Frank et al., 2015; McGlashan et al., 2018; Norcross et al., 2016). Though general injury statistics can build assurance for some teams, some remain sceptical of the relevance of a programme to their team (Gokeler et al., 2018; Norcross et al., 2016; O'Brien & Finch, 2014). IPP implementors need evidence the programme improves player or team performance, beyond injury reduction to accept it (Hägglund et al., 2013; O'Brien & Finch, 2014; Richmond et al., 2020). Implementors want an empirically designed programme that meets the demands of their team, considering age group, skill level, gender, need for progression and best practice dosage requirements (Lindblom et al., 2018; McGlashan et al., 2018; O'Brien & Finch, 2014; White et al., 2012). Similarly, stakeholders want evidence to support that an IPP is ‘up-to-date’. An advertised programme should utilise innovative knowledge, if it wishes to be acknowledged and maintained throughout several seasons (Dahlström et al., 2015; Lindblom et al., 2018; Martinez et al., 2017; Norcross et al., 2016). Key stakeholders must believe that the endorsed IPP is superior to what they are already performing, that injuries will decrease further, performance improve and players become more frequently available for games (Lindblom et al., 2018; McGlashan et al., 2018; E. M. Rogers, 2002).

Recognisable.

One of the consistent reasons given for failed IPP acceptance and dissemination, is that the research driven content of the programme lacks real-world legitimacy (Lindblom et al., 2018; Richmond et al., 2020; White et al., 2012). To counter-act this exercises need to be perceived by the end-users as being normal exercises/movements seen within their sport (sport specific) (Norcross et al., 2016; O'Brien & Finch, 2014; Saunders et al., 2010). The IPP must fit into their normal training, game routine and the exercises should be somewhat recognisable (Ageberg et al., 2019; Donaldson et al., 2018; White et al., 2012). Research suggests that sport specific exercises are not essential, instead exercises must only be recognisable in nature from existing and accepted injury prevention movements (Norcross et al., 2016; Richmond et al., 2020). The content of several national warm-up IPPs (FIFA 11+, NetballSmart, BokSmart, RugbySmart) for instance have similar exercises, which all appear to reduce injury risk (Belcher, Whatman, Brughelli, & Borotkanics, 2021; Brown, Verhagen, Knol, Van Mechelen, & Lambert, 2016; Fulcher et al., 2018; Steffen et al., 2013). However, most evidence still shows that if coaches and players perceive a programme to imitate movements more specific to their sport, they are more likely to perform the IPP (Finch et al., 2014; O'Brien & Finch, 2014; Saunders et al., 2010). Many key influencers are driven by what they perceive as social norms, if other teams, coaches and players are using an IPP then why shouldn't they? Coaches who have seen IPPs used with other teams or who have greater experience looking after older or more proficient teams (>7 years), are more likely to believe in the worth of an IPP (Joy et al., 2013). The more frequently coaches see other teams utilise and IPP, the increased likelihood they will perceive its use as normal practice (Dahlström et al., 2015; McKay et al., 2014; White et al., 2012). Lastly, an IPP should recognise the effect of an individual's injury history to promote the efficacy of the programme. Those that have suffered previous significant injuries are often more supportive of an IPPs benefits, believing if they had been exposed to a programme prior to receiving the injury, they would never have been injured (Gokeler et al., 2018; McKay et al., 2014). This evidence suggests that an IPP should strive to educate their end-users on why recognisable exercises in the programme would benefit their team, specifically utilising their direct peers and role models through differing mediums to highlight its success.

Adaptable

One of the cited barriers to compliance is rigid or unrealistic exercise content (Donaldson et al., 2016; Gokeler et al., 2018). Many find exercises in IPPs too complex for younger or inexperienced players and that programmes fail to meet age or skill specific requirement. The exercises may be unsuitable for young children, due to a lack of strength, fitness, motor skill development or maturation capability (Ageberg et al., 2019; Lindblom et al., 2018; Richmond et al., 2020). A programme that either has age, motor skill or maturation level specific exercises and can progress with growth and development would be of great benefit to youth coaches (Ageberg et al., 2019; Emery et al., 2015; Richmond et al., 2020). Similarly, many community players compete at a lower skill level and possibly lack the base fitness or motor skills required to perform some exercises. A programme that can adapt for everyone within a teams varied skills levels, is likely to be employed more frequently (Donaldson et al., 2016; Richmond et al., 2020; Saunders et al., 2010). Conversely, other studies have reported that IPPs fail to provide suitable progressions to meet the demands of higher performing players, leading to boredom and reduction in compliance (Ageberg et al., 2019; Donaldson et al., 2016; O'Brien & Finch, 2014). Additionally, a lack of variation in the programme content has been cited as a barrier (Finch et al., 2014; O'Brien & Finch, 2014; Sugimoto et al., 2014). After performing the same programme over several seasons players and coaches lose motivation. If exercises can be adapted to be more fun (Saunders et al., 2010), sport specific (Emery et al., 2015; Myklebust et al., 2013) or transition into game skills (Ageberg et al., 2019; Finch et al., 2014), they are more likely to be maintained. An IPP that can be adjusted to meet team specific training goals or replicate recognisable drills, performed in the teams usual training environment, will have greater acceptance (Finch et al., 2014; Lindblom et al., 2018; McGlashan et al., 2018; Norcross et al., 2016). However, research indicates that education on exercise selection and its relevance to their sport is not enough, key influencers would also like information on how to adapt the programme to better meet team needs (youth, greater or lesser skill/experience and gender specific) (Donaldson et al., 2018; O'Brien & Finch, 2014; Saunders et al., 2010).

Overcoming logistical barriers

A frequently cited barrier for failed IPP/warm-up implementation is lack of time and additional equipment to perform the programme effectively (Donaldson et al., 2016; Finch et al., 2014; Lindblom et al., 2018; Richmond et al., 2020; Saunders et al., 2010; Sugimoto et al., 2014). Often coaches, and players indicate that an IPP takes up too much of their training time, does not fit into their session goals or interferes with higher priorities during heavy competition periods (Lindblom et al., 2018). This leads to most teams modifying and shortening longer IPPs, whilst retaining some game specific movements which can be transitioned straight into skill sessions (Donaldson et al., 2018; Finch et al., 2014; Lindblom et al., 2018; Saunders et al., 2010). However, the effectiveness of previous warm-up IPPs has largely been based on programmes that are ≥20mins in length (Belcher et al., 2021; Emery et al., 2015; Fulcher et al., 2018; Steffen et al., 2013). Previous research suggests longer duration programmes (> 20 min), conducted more frequently (> three times per week), have greater effect (Soligard et al., 2010; Steffen et al., 2013). There is some concern a shortened IPP therefore is less likely to achieve efficacious results. However, early evidence would suggest that short duration programmes with fewer exercises can still be beneficial, such as BokSmart (Brown et al., 2016), a basketball warm-up (Aerts et al., 2015) and the NetballSmart Power Warm-up (Belcher et al., 2021). Further research into the effectiveness of short duration IPPs, would be beneficial for programme design in the future. Another factor that can increase the duration of an IPP, is the need to remove and set-up equipment (Donaldson et al., 2018; O'Brien & Finch, 2014; Richmond et al., 2020). The need for equipment can be a detriment to programme implementation, due to cost, space to perform the exercises or store the gear and the additional time involved (O'Brien & Finch, 2014; Richmond et al., 2020).

To reduce logistical barriers IPP's should have the ability to be modified to meet the skill, fitness and growth demands of the team. There should be some education on how to add components to the programme, whilst retaining fidelity, thus increasing motivation and enjoyment. An IPP should preferably be short in nature, but still consist of evidence-based sport specific exercises that allow for the ability to smoothly transition programme content into training skill sessions. Finally, there should be limited need for equipment within the IPP (that which is used should be sport specific, e.g correct ball shape), to reduce duration, cost and aid the ability for the programme to be performed in any environment.

Implementation (n = 31)

Education, professional development and Support

A further barrier is the lack of self-efficacy those implementing the programme feel, believing they lack the required skills to obtain positive results (Frank et al., 2015; Martinez et al., 2017; Padua et al., 2014). The lack of self-efficacy stems largely from feelings of inadequate knowledge about the programme content or benefits and inability to access further feedback and support to improve their skills (Donaldson et al., 2018; Joy et al., 2013; Lindblom et al., 2018). Research indicates that greater education on how to adapt the programme to better meet their team's needs (youth, greater or lesser skill/experience and gender specific), would increase key influencers self-efficacy of running a programme (Donaldson et al., 2018; O'Brien & Finch, 2014; Saunders et al., 2010). Coaches want access to further educational workshop options, containing empirically researched exercise progressions or individual player development suggestions (Dahlström et al., 2015; McGlashan et al., 2018; Padua et al., 2014). An accredited educational IPP for coaches is often mentioned as a facilitator to programme implementation, starting with the basic knowledge for lower skilled coaches though to high-performance (McGlashan et al., 2018; Norcross et al., 2016; Saunders et al., 2010). It is believed self-efficacy for coaches and players would grow if they have been accredited or licensed in some way (DiStefano et al., 2017; Joy et al., 2013; Saunders et al., 2010). Similarly, players and coaches have increased confidence and show improved adherence to an IPP, if those leading the programme have undergone a practical workshop prior to implementation (McKay et al., 2014; Steffen et al., 2013). Another way to develop self-efficacy amongst coaches is access to feedback and support sessions with their fellow coaching peers and experts in the field. Coaches have indicated they would feel more confident to utilise the IPP and further adapt the programme to meet their teams need, if they could gain insights on how to do so from other coaches (Lindblom et al., 2018; McGlashan et al., 2018; Richmond et al., 2020). An IPP that offers the equivalent of a 'coach/player helpline' and access to regular peer meetings as part of its implementation design, will more likely show continued success.

Authors suggest that educational workshops can be presented in a variety of forms. Informal discussions or fun physical game sessions amongst youths and coaches alike are often effective (Ageberg et al., 2019; Donaldson et al., 2017; Richmond et al., 2020). Likewise, more informal public meetings at clubs or schools can offer an opportunity to share information with a larger number of the community or specific stakeholders such as parents (Bekker et al., 2017; McGlashan et al., 2018). Alternatively, several studies have specified that organisations and coaches would comply to an IPP if formal training was added to the coaching curriculum, with an ability to start at a foundation level and progress through to high-performance (Donaldson & Finch, 2013; Emery et al., 2015; McGlashan et al., 2018; Saunders et al., 2010). Coaches want to feel they have been rewarded for their attempts at self-development and learning (Donaldson et al., 2017; McGlashan et al., 2018; Saunders et al., 2010). The language coaches use to teach the players movement or technique skills can play an important part to IPP compliance. An IPP workshop that teaches coaches to use a variety of internal and external focus instructions to teach motor skills to their players, is likely to increase the quality of movement performance and acceptance by the team (Gokeler et al., 2018; McGlashan et al., 2018). Similarly, use of positive reinforcement over negative feedback improves self-efficacy and respect from coaches undergoing a practical training workshop on learning exercise technique correction (Gokeler et al., 2018; McGlashan et al., 2018; Padua et al., 2014). Focusing on positive language and how their teaching performance can improve, rather than their shortcomings builds confidence in stakeholders being instructed. The overriding message is that after undergoing a comprehensive educational workshop on an IPP application, the key stakeholder (organisation, coach, player) self-efficacy grows and their willingness to disseminate and endorse the programme is greater (Bekker & Clark, 2016; Donaldson et al., 2016; Steffen et al., 2013). Research would also suggest that endorsement of practical IPP coaching workshops at an organisational level may be key to better propagation and maintenance of a programme's success within the sports community (Ageberg et al., 2019; Fulcher et al., 2018; McGlashan et al., 2018; Norcross et al., 2016).

Poor advertising of how to access educational workshops is often mentioned as a barrier for implementors/end-users (Emery et al., 2015; McGlashan et al., 2018; Norcross et al., 2016). As IPP educational workshops are important to implementation, being able to geographically access them with ease is very important. Having a network of travelling coaches or ambassadors that can teach these workshops locally in the sports centre, directly in the school or club environment is beneficial. (Fulcher et al., 2018; Padua et al., 2014; Richmond et al., 2020). Coaches are also more likely to feel comfortable learning from an educational programme that is run in an environment they know well and in which they can potentially practice transferable skills directly in their training setting (McGlashan et al., 2018; Richmond et al., 2020). For educational workshops to be presented in the end-users' own environment requires access to a maintainable and significant funding source, thus poor financial resources can act as a barrier to implementation of a programme on a grander scale. Likewise, if training costs too much it is unlikely to be utilised frequently or remain viable (Fulcher et al., 2018; Norcross et al., 2016). However, existing research shows IPPs can be economical, especially when accounting for the cost serious injury places on a national system. Fulcher et al. (2018), showed a return on investment as high as NZD$8.10 for every dollar spent on an IPP and others have shown anywhere from 24-150 ACL injuries could be prevented with the cost it takes for a single surgical repair (LaBella et al., 2011; Swart et al., 2014). It seems the barrier of cost is probably more perceptual, especially as many IPP have been designed to cost very little to run for an individual team (Emery et al., 2015; Lindblom et al., 2018; Norcross et al., 2016).

Resource development

It has been suggested that purely passive diffusion of IPP education via leaflets, coaching booklets, DVD and online resources is not effective in gaining success (Bekker et al., 2017; Saunders et al., 2010; Steffen et al., 2013). However, many end-users believe passive educational resources can act as a type of feedback or revision of information from educational workshops and therefore still have their place in building self-efficacy and implementation of IPPs (Donaldson & Finch, 2013; Myklebust et al., 2013; Saunders et al., 2010; Steffen et al., 2013). IPP content is often developed from academic research by health/sports scientists, all of whom frequently use specialist language to communicate. When exercise descriptions and instructions are written into resource material for an IPP they are often too scientific, and this unsuitable language can easily confuse the layman coach or player (Donaldson et al., 2016; Richmond et al., 2020; Saunders et al., 2010). This research-to-practice translation failure can affect the end-user's self-efficacy, as they lose confidence in their understanding and capability of running the programme effectively (Donaldson et al., 2017; Gokeler et al., 2018; O'Brien & Finch, 2014; Richmond et al., 2020). Utilising multi-disciplinary key stakeholders to collaborate on the written language of a resource can therefore be beneficial (Bekker & Clark, 2016; Bekker et al., 2017; McGlashan et al., 2018). Informative resources created for the IPP should be easily accessible in many different mediums, such as internet pages, paper formats, booklets and social media adverts. This offers the greatest chance for dissemination to the community and all stakeholders.[2,24,48] An easy-to-understand coaching/player 'toolkit', which offers foundation information and teaching tools on how to translate IPP content to 'real-world' training, has been suggested as a positive facilitation instrument (Lindblom et al., 2018; Padua et al., 2014;

Richmond et al., 2020).

Ambassadors and role models

Another way to further legitimise and build adherence to an IPP is to have respected coaches and players act as ambassadors/role models, endorsing the programmes worth (Bizzini, Junge, & Dvorak, 2013; Donaldson et al., 2016; McGlashan et al., 2018; Poulos & Donaldson, 2012). These role models do not always have to be high profile sports personalities, instead they can be respected peers/members of the community. This is particularly the case for youth players and low experience community coaches (Emery et al., 2015; Lindblom et al., 2018). Similarly, this is the case for several New Zealand communities, Māori, and Pasifika populations. These ethnic groups place significant trust in information given by role models or respected members of their communities and learn best from their stories or practices (Hapeta, Palmer, Kuroda & Hermansson, 2019). Community level teams would sometimes prefer the IPP education be shared by respected peers over a high-profile personality, as they feel more comfortable sharing ideas and asking questions amongst those that are closer to their level (Lindblom et al., 2018; McGlashan et al., 2018; White et al., 2012). An opportunity to gain some support and feedback from a peer group, is deemed desirable by many players and coaches alike (Lindblom et al., 2018; McGlashan et al., 2018; Richmond et al., 2020). High-profile ambassadors can also play a role in the promotion of an IPP, advertising its worth through an array of social media platforms, leading to greater acceptance and uptake by the sporting community (Bruder et al., 2020; Myklebust et al., 2013; Storey, Saffitz & Rimon, 2008).

Social media and promotional plans

Designing a social media plan when implementing an IPP in the modern climate, is essential to greater dissemination (Bekker et al., 2017; Donaldson et al., 2017; Fulcher et al., 2018). Social media is an important medium for promoting educational workshops, new resources or research material and key messages or content for the IPP. For social media to reach a greater proportion of the community, it must be designed with a specific target audience in mind (McGlashan et al., 2018; Storey et al., 2008). Once again if the end-user does not believe the message they are receiving meets their personal or team needs, they are unlikely to retain or apply any of the information given (Donaldson et al., 2016; McGlashan et al., 2018; Myklebust et al., 2013). The use of websites (Fulcher et al., 2018; Saunders et al., 2010; Steffen et al., 2013), DVD material (Donaldson & Finch, 2013; Donaldson et al., 2016; Myklebust et al., 2013), television media adverts (Fulcher et al., 2018; Lindblom et al., 2018; McGlashan et al., 2018), written leaflets and booklet resources (Ageberg et al., 2019; Richmond et al., 2020; Steffen et al., 2013) have also be found to be useful methods of promotion. It would therefore be prudent to create a promotion plan for wider implementation of an IPP, using an array of different mediums to get the education and information across to the often quite varied audiences. Finally, using commonly recognisable language in resources can also act as an important facilitator in promotion material or social media campaigns (Storey, 2008). Shaping your language and messaging carefully, when advertising an IPP can make a significant difference to its uptake amongst the community (Bekker, 2017; Storey et al., 2008). This is especially the case when attempting to disseminate information within New Zealand cultural groups (Māori and Pasifika), who in the first instance may resonate with the messaging more confidently if it is written in their native language (Hapeta et al., 2019).

Therefore, an IPP requires a multi-faceted variety of educational workshop and resource formats, with sport and audience specific content to successfully be implemented amongst the larger sporting community. Choosing inappropriate language or role models that do not resonate with the audience you are aiming to influence will likely reduce the spread of a programme (Hanson et al., 2012; McGlashan et al., 2018; Storey et al., 2008). The programme and practical workshops should be easily accessible wherever the user is geographically. Creating a sound advertising and promotional plan is essential for greater dissemination and likely credibility to the programme. Finally, those implementing or using the programme should be given opportunities to progress their knowledge and skills, whilst being offered feedback support systems to build self-efficacy.

Conclusion

Though it can be a challenge turning a research grounded IPP into one that is practically accepted by the general populous and more importantly sustained, it is possible. The findings of the review identified four key themes that recognised common facilitating factors, as well as frequent barriers to implementation. Based on the evidence presented in this review we suggest the following practical guide to overcome barriers to implementation and maximise IPP implementation in the real-world setting. The proposed steps (Figure 1) represent a cyclic process that allows ongoing review of IPPs at regular intervals (e.g., annually).

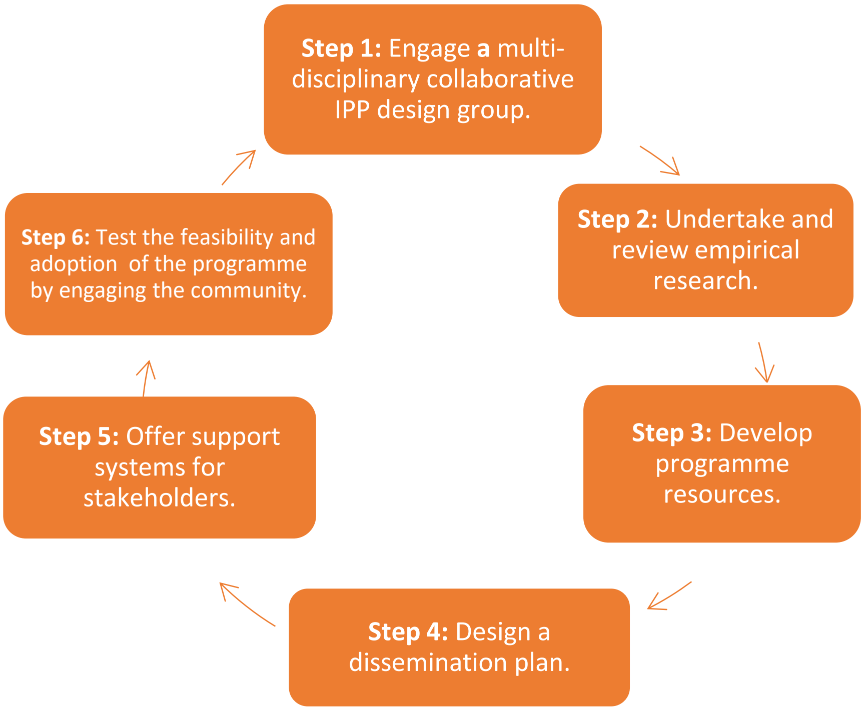


Figure 1. Proposed cyclic process for IPP implementation.

Real-world Guide to Implementation

Step 1: Establish a multi-disciplinary and multi-level collaborative IPP design group containing all key stakeholders and research personnel. This group will discuss targeted drives/priorities for research that offers 'real-world' practical advice for the community, along with innovative ways to logistically 'roll-out' the programme. Collaboration also builds a sense of ownership and shared control over an IPP by stakeholders, giving more credence to the content and positive behavioural change to implementation. Similarly, a programme endorsed by the national sporting body and respected members of the community, is more likely to be accepted by others.

Step 2: Undertake and review empirical research gathered from a range of research areas/fields (Cadaveric, Computational models, Video analysis, epidemiological and laboratory) in the area, including expert opinion from key members of the sporting community. Early epidemiological research will give a clearer picture of the most common injuries, which target age groups are at risk (therefore audience for programme delivery) and if there are any seasonal patterns in injury to focus IPP content towards. This evidence will help determine the content of the messaging for the IPP, how to fashion the design and language for the various key audience groups. The findings from research will guide the information given in the practical workshops, as well as teaching tips for coaches to improve fidelity and effectiveness of the IPP. The research can also be used to attract funding sources, which in turn can hire programme ambassadors/educators, finance promotional and resource material and inevitably increase access to the programme.

Step 3: Develop resources for the programme in a variety of formats, including video, website, infographics, workshop booklets. Insert the IPP resources within coaching and player workshop booklets from foundation junior, through all levels. Educational workshop content must also offer levels of skill development from foundation to high performance. The content of the programme must be modifiable to meet the varied needs of the users (age, gender, skill level). Imbedding the workshops in an accredited coaching framework or player development programme, will allow those learning a feeling of achievement/competence and increase their respect for the course.

Step 4: Design a thorough dissemination plan, with focus on promotional advertising through social media, television adverts and written releases. Employ respected and/or well-known sporting personalities to endorse the programme. Apply social media to advertise educational workshops in the area and highlight their geographical spread and ease of access for the community. Build a network of travelling coaches or ambassadors that can teach these workshops locally in the sports centre, directly in the school or club environment, making them geographically accessible to as many as possible.

Step 5: Offer support systems for stakeholders so they can gain feedback on the performance of the IPP and how to adapt or progress it further to better suit their players needs and values. Offer the equivalent of a coach/player ‘helpline’ or peer informal gatherings to discuss programme use and building self-efficacy amongst those that implement the programme. Likewise, an opportunity to gain feedback and support from sport/health science researchers and professionals will be beneficial and allow new evidence to be available to those implementing/using the IPP.

Step 6: Evaluate the feasibility and adoption of the IPP resources and messaging. This can be done via a variety of methodologies including intervention studies, focus groups, surveys or questionnaires within the community to gain feedback on IPP effectiveness. Use this information to recognise possible barriers to dissemination and any adaption or improvements that would benefit programme effectiveness and sustainability. Collect data from an assortment of channels to monitor the success of the IPP (injury databases, compliance requirements, branding notability) and use this information to build programme maintenance strategies.

CHAPTER THREE: TEN-YEAR NATIONWIDE REVIEW OF NETBALL ANKLE AND KNEE INJURIES IN NEW ZEALAND.

Prelude

The narrative review in chapter two identified the need to gather empirical evidence regarding key body areas, target audiences and seasonal time-periods netball players are most at risk of injury. The findings of this evidence could then guide resource and education workshop development for the NIPP. This ten-year review of injury was undertaken in-part to satisfy this recommendation and further refine the direction of the NIPP 3-year implementation plan.

This chapter comprises the following paper published in: Journal of Science and Medicine in Sport.

Belcher, S., Whatman, C., Brughelli, M., & Borotkanics, R. (2020) Ten-year nationwide review of netball ankle and knee injuries in New Zealand. *Journal of Science and Medicine in Sport, 23*(10):937-942.

Abstract

Objectives: To review netball ankle and knee injuries between 2008 and 2017.

Design: Audit of insurance injury claims.

Methods: Data were divided into 5 equal year groups (2008/9, 2010/11, 2012/13, 2014/15, 2016/17), and 3 age groups (10 to 14 years, 15 to 19 years, 20 to 24 years old). Raw injury counts and annual injury rate per 1000 affiliated players per year were reported. Changes in injury prevalence over the 10-year period and differences between age groups were expressed as incidence rate ratios (IRRs). A Shewhart control chart was created to identify monthly injury patterns.

Results: 10-14-year-olds showed the biggest increase in injury counts (ankle 84% increase and knee 133% increase). 20-24-year-olds had the highest annual injury rate over the ten-years (ankle=77.8, knee=71.6 injuries/1000 players). 10-14-year-olds had the biggest increase in risk of injury between 2008/09 to 2016/17, (ankle IRR = 2.0; knee IRR = 2.5), 15-19-year-olds (ankle IRR = 1.4; knee IRR = 1.5), 20–24-year-olds (ankle IRR = 0.5; knee IRR =1.9). The older two groups had a significantly higher mean risk of ankle and knee injury (IRR = 1.9 to 2.2; $p < 0.001$). Higher than expected yearly injury incidence was repeatedly seen in 10-19-year-olds.

Conclusion: Ankle and knee injuries have increased with the biggest increase in 10-19-year-olds. Injuries in 20-24-year-olds still represent the highest cost and continue at a higher rate than in younger players. Spikes in injury are likely associated with intense periods of trialling and

tournament play.

Keywords: Sports Medicine, Epidemiology, Insurance, Prevention, Sports

Introduction

Participation in netball is predominately female and is currently played in over 70 countries (Hetherington et al., 2009). A key rule that separates netball from similar sports is that players can only take a maximum of one and half steps whilst in possession of the ball, resulting in repeated rapid decelerations to avoid violating this rule (Hopper et al., 2017). This rapid reduction in horizontal velocity during jump and change of direction movements, whilst attempting to maintain balance poses a high injury risk to the lower extremity, specifically ankles and knees (McManus et al., 2006; Stuelcken et al., 2013). The ankle and knee are frequently cited as the most prevalent body areas for injury in the game of netball (Hopper et al., 1995; Joseph et al., 2019; Langeveld et al., 2012).

Netball New Zealand (NNZ) and Accident Compensation Corporation (ACC) (a no-fault national insurance system) wish to reduce injuries and have developed a netball specific national injury prevention program (IPP) called ‘NetballSmart’(Fulcher et al., 2018). A successful IPP requires a holistic approach that encompasses analysing the whole games landscape, whilst targeting the correct audiences for specific education (Saunders et al., 2010). Epidemiological research can guide the focus of an IPP by identifying any seasonal injury patterns, the target audience for program content and which body areas are most at risk (Brooks & Fuller, 2006).

Unfortunately, there remains very few studies worldwide on the epidemiology of netball injuries. Existing published papers have centered around tracking individual teams over a limited period-of-time, rather than reviewing nationwide injury datasets (Hopper et al., 1995; Langeveld et al., 2012). Studies often fail to account for training injuries or obtain competition event injuries only. A few studies have investigated national cohorts of injury data over several years in Australia (Flood & Harrison, 2009; Joseph et al., 2019) and New Zealand (NZ) (King et al., 2019). However, these studies indicated limitations in their dataset, as they were unable to identify a more comprehensive proportion of the population’s injuries or garner quality participation data to calculate risk or rate of injury. Data that can express a risk or rate of injury allows IPPs to efficiently validate where best to utilise resources, determine the priority audiences for education and highlight which age groups require further investigation on cause of injury. Number of injuries alone will not determine which participants are at most risk of injury.

Injury rates in sport can vary due to numbers of at-risk participants and the ratio of training/competition hours. Previous studies have indicated injuries are more frequent during competition (Flood & Harrison, 2009; Otago & Peake, 2007). Therefore, high-density periods of competition (tournaments, team selection and end of season games) where players are exposed to several games in a day or on consecutive days without adequate rest, may be expected to increase injury rates. Evaluating seasonal demands of the game, in terms of increased competition periods and their subsequent effect on injury rates, could help inform the structure of a national program. Total count of injuries determines cost to ACC, a key outcome when evaluating the success of an IPP in NZ, and thus will be included in this study. As ankle and knee injuries constituted 47% of all netball injury claims for the year 2017 and 66% of the cost of netball injuries to ACC at NZD$18,049,370, further evaluation of data for these two body areas remains a priority for the NNZ community. Additionally, using national affiliated member numbers obtained from NNZ allows calculation of injury prevalence and more appropriate evaluation of changes over time.

With these observations in mind, the aim of this study was to review counts and rates of netball ankle and knee injuries in NZ over a 10-year period, with a focus on seasonal changes and age group differences.

Methods

Data Extraction Process

ACC requires little immediate financial input from injured parties, so it is common for even minor sports injuries to be registered (Fulcher et al., 2018; King et al., 2019). Many other systems throughout the world capture only a small proportion of a populations injuries, as databases are not centralised (public or private only). Epidemiological data were extracted from ACC (Ethics ref45909). Key search criteria for claim extraction included: count of new netball related claims by body site, seasonal changes, age groups and registered between Jan 1st, 2008 to December 31st, 2017. Data was excluded from this study if individual claims had fewer than 4 treatment sessions or cost <=$100, an underlying ACC privacy policy for release of data to external researchers (https://docplayer.net/23441186-Application-guide-to-assist-completion-of-the-acc-research-ethics-committee-application-template.html).

Data Organization

The data were organized into five time periods (2008/9, 2010/11, 2012/13, 2014/15, 2016/17), and three age groups (Group 1= 10-14-years, Group 2= 15-19-years and Group 3= 20-24-years old). These age groups were chosen as they ranked highest for ankle and knee injuries over the 10-years. The dataset was initially described as simple injury counts, as this represents cost of all injuries to ACC. Annual injury rate was calculated as number of netball injuries per 1,000 affiliated membership population per year. Affiliated member numbers were sourced from NNZ and placed into age brackets mirroring those described in ACC data. Any costs described in the paper are corrected for inflation using the Reserve Bank inflation adjuster consumer price index (CPI) (https://www.rbnz.govt.nz/monetary-policy/inflation-calculator), reflecting costs standardised to 2017. Ethical consent for the research was reviewed by Auckland University of Technology Ethics Committee (AUTEC).

Data Analysis

Difference in injury rate between 2008/9 and 2016/17, for each individual age group was investigated and results presented as incidence rate ratio (IRR) with 95% confidence intervals (CI). Comparison of injury rate between each age group over the 10-year period was analysed with Poisson regression analysis. The youngest age group 10-14-year-olds (Group 1) acted as the reference group for the Poisson regression and the outcomes also expressed as an IRR.

Additionally, seasonal changes for each age group were investigated using a Shewhart control chart for combined ankle and knee injuries over the ten-years. These charts identify systematic patterns of excessive injury count for the season, giving a running record of behaviour over time (Rakitzis, Castagliola, & Maravelakis, 2016). This control chart depicts first a mean control line or average number of ankle and knee injury counts for all age groups over the 10-year-period. Then an upper-control limit is plotted as 3 standard deviations above the mean control line. The upper limit detects worsening injury incidence over the months of the year and has been used in similar studies to evaluate patterns in illness or disease (Rakitzis et al., 2016). Control charts were derived using Microsoft Excel 2016 (Microsoft, Washington, U.S.) spreadsheets. All other statistical analyses were carried out using Stata V. 15.1 (StataCorp LLC., Texas, USA).

Results

The youngest age group (10-14-years-olds) showed the highest percentage increase in injury counts between 2008 and 2017 for both ankle (84% increase) and knee (133% increase) injuries (Table 1). Injury counts also increased in the 15-19-year-olds (ankle=37% increase and knee=49% increase). In the 20-24-year-olds ankle injuries decreased (7%), while knee injuries increased (30%). Visual inspection of Table 1 suggests there was a small decline in the count of ankle and knee injuries, across all age groups since 2015.

Table1. Injury counts for the three age groups, along with percentage increase change for each year group.

Age Groups	2008-09		2010-11		2012-13		2014-15		2016-17		% change between 2008-17
	Count	%	Count	%	Count	%	count	%	count	%	
Ankle 10-14	2757	–	3338	21%	4396	32%	5491	25%	5064	-8%	84%
Ankle 15-19	3047	–	3358	10%	4173	24%	4388	5%	4162	-5%	37%
Ankle 20-24	2202	–	2384	8%	2537	6%	2411	-5%	2046	-15%	-7%
Knee 10-14	1219	–	1506	24%	2230	48%	2997	34%	2841	-5%	133%
Knee 15-19	1334	–	1576	18%	2101	33%	2251	7%	1985	-12%	49%
Knee 20-24	928	–	1073	16%	1185	10%	1321	12%	1207	-9%	30%

Comparing injury risk in 2016/17 to 2008/9, based on proportion of affiliated members injured, the risk of ankle injuries has reduced (IRR=0.5, CI 0.5-0.6) and the risk of knee injuries increased (IRR=1.9, CI 1.7-2.0) in 20-24-year-olds. In contrast, 10-14-year-olds were 1.9 (CI 1.9-2.1) times more likely to have an ankle injury and 2.5 (CI 2.4-2.7) times more likely to have a knee injury in 2016/17 compared to 2008/9, and 15-19-year-olds were 1.4 (CI 1.4-1.5) times more likely to have an ankle injury and 1.5 (CI 1.4-1.6) times more likely to have a knee injury.

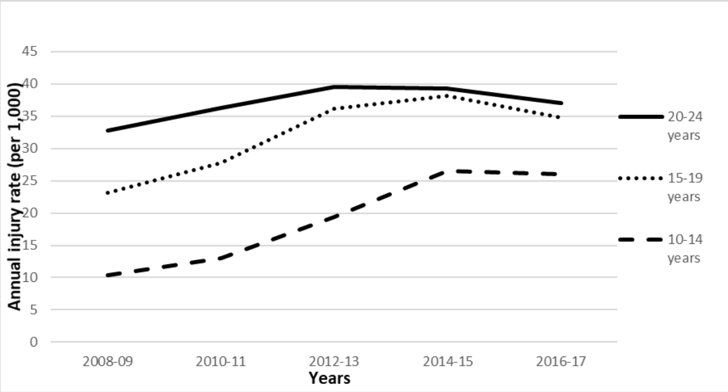


Fig 1a Knee annual injury rate per 1000 members per year for the three age groups, between 2008-2017

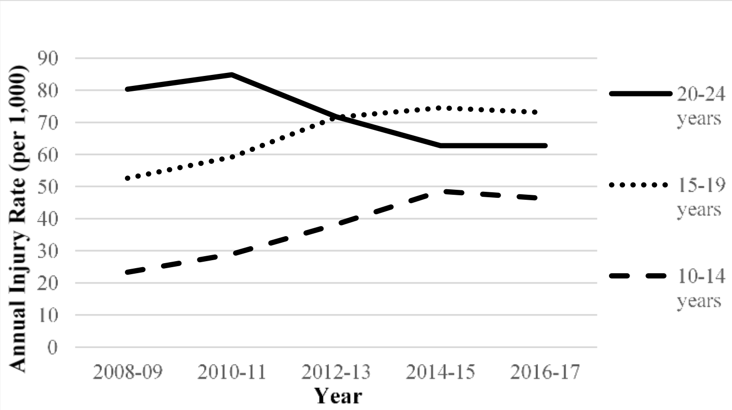


Fig 1b Ankle annual injury rate per 1000 members per year for the three age groups, between 2008-2017

Fig. 1. (a) Knee annual injury rate per 1000 members per year for the three age groups, between 2008-2017. (b) Ankle annual injury rate per 1000 members per year for the three age groups, between 2008-2017.

When injury rate was calculated using affiliated member numbers, the 20–24-year-olds exhibited the highest mean injury rate over the ten-year period (ankle=72 knee=37 injuries/1,000 players) compared to 15–19-year-olds (ankle=67, knee=32 injuries/1,000 members) and 10-14 years olds (ankle=37, knee=19 injuries/1,000 members) (Fig. 1a-b).

Supplementary tables of the affiliated membership numbers by age group and year, Poisson regression results and IRR for changes over the ten-year period has been produced for the benefit of those wishing to further explore the data, but not included in the main body of this paper. Reviewing the Poisson regression analysis comparing the differences between groups for each time period over the ten-years, both older age groups had a higher rate of ankle (IRR=1.3

to 3.5; p<0.001) and knee (IRR=1.3 and 3.2; p<0.001) injuries than the youngest group.

Visual inspection of the Shewhart control chart (Fig. 2) shows that every month of May from 2013-2017, injury counts in the two younger age groups (15-19year-olds) cross the upper-incidence control line, suggesting excessive increase in injury count. A distinctive yearly pattern of spiking injury starting in March and peaking in May and then a subsequent increase between July-August can also be seen in both younger age groups (Fig. 2). The rise of injury at the beginning of the season in May, was markedly higher than the one in August. There was no clear seasonal pattern of injuries in the 20-24-year-olds.

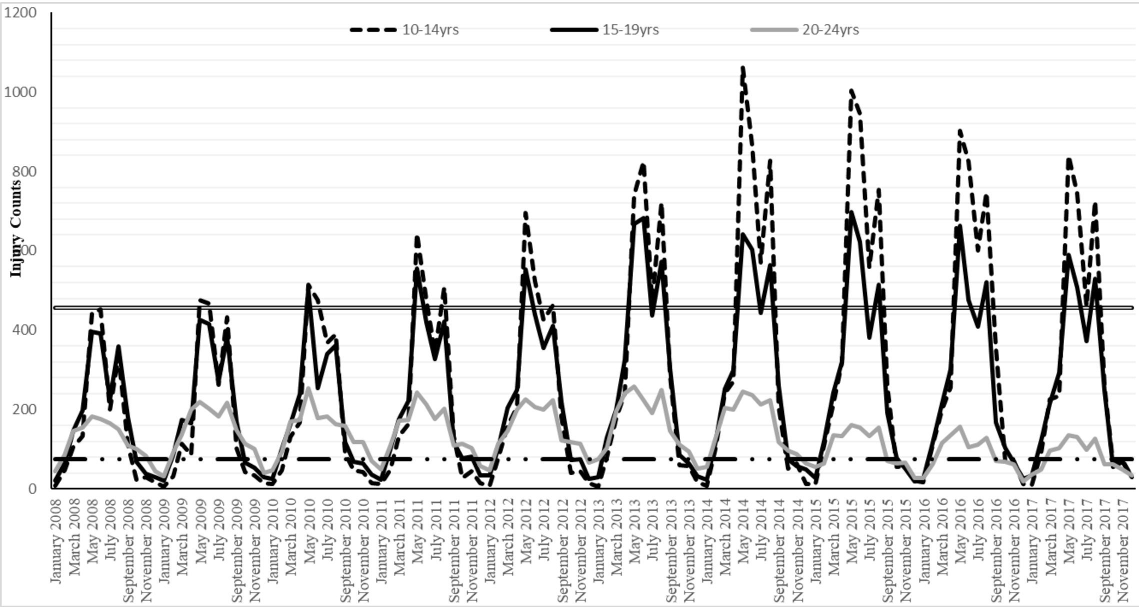


Fig 2 Seasonal injury counts for the three age groups over the ten-year period. **Mean Control Line= average number of ankle and knee injury counts for all age groups over the 10-year-period. *Upper Control Limit= 3 standard deviations above the mean control line (above line=extreme injury counts)

Discussion

This largescale retrospective cohort design used detailed epidemiological data, acquired from ACC from 2008-2017 to investigate ankle and knee netball injuries. This research adds to previous reports on ACC data that focused on severity and cost of injury amongst NZ top five most popular sports, including netball (King et al., 2019).

Findings from this study reveal an increasing count of knee injuries in all age groups and increasing ankle injuries in the two youngest age groups over the last 10-years. Comparing 2008/9 to 2016/7 the largest percentage increase in ankle and knee injury count and prevalence was found in the youngest age 10-14-year age group. This group are approximately twice as likely to report an ankle or knee injury in 2016/7 compared to 2008/9. The 15-19-year-old group had the second largest increase in injury count and prevalence. One explanation for increased injury numbers in the 10-19-year-old group, is the suggestion that female's post-puberty show rapidly changing physiological growth developments and hormonal changes, that can lead to reduced lower extremity neuromuscular control when landing (Hewett et al., 2006; McManus et al., 2006). These physiological changes can present as: reduced balance control on landing, an over reliance on the dominant limb, muscle strength imbalance between quadriceps and hamstrings, decreased activity of hip musculature and reduced postural stability (Hewett et al., 2006; Murphy et al., 2003). These changes can cause a stiff-leg poor landing mechanism, which may increase the risk of knee and ankle injury (Murphy et al., 2003; Myer et al., 2009). An IPP targeted towards the 10-19-year-old age group should focus on educating players to improve motor control and landing technique prior to and throughout maturation (Hewett et al., 2006; Root et al., 2015). Another reason this age group may show greater counts of injury, is their possible participation in several teams (school, club and representative). The increased exposure time of playing with several teams, would likely place these young players at greater risk, whereas the 20-24-year-olds would not be eligible for school or age group representative teams, so have a reduced exposure to the game (Caparrós et al., 2016). With increasing count and rate of injury in 10-19-year-olds over the ten-years it is clear a national IPP should continue to target these players (Fulcher et al., 2018; Whatman & Reid, 2017).

Though poor neuromuscular control during adolescent growth may account for why female youth are at risk of injury, it cannot necessarily clarify the increase in injury over the ten-years. In the last few decades, the adolescent sport experience in many western countries has begun to change, including NZ (Bergeron et al., 2015; Blagrove, Bruinvels, & Read, 2017). The result of this trend is an increase in professionalisation, intensified training, with greater competition volume and frequency from an early age (Blagrove et al., 2017). These factors coupled with insufficient allocation of rest and recovery time throughout the season can lead to ongoing escalation in sport-related injuries and health problems at all levels of youth sports (Bergeron et al., 2015; Blagrove et al., 2017; DiFiori et al., 2014). Perhaps these alterations in behaviour and attitude in youth sport over the last few decades, may in some measure increased injury counts in 10-19-year-olds in NZ (Bergeron et al., 2015; Rogers & Cassidy, 2015).

Our findings suggest a reduction in ankle and knee injury counts between 2015-17, which could be due to a combination of decreased participation numbers (approx. 9.9%) and an increase in sport specific injury prevention funding by ACC (Fulcher et al., 2018). Additionally, 'NetballSmart' the NZ IPP introduced its education programs on a larger scale nationally after 2015, including how to improve neuromuscular movement control, safe warm-up preparation and reduced loading for youth players.

Although the raw number of ankle and knee injury counts were highest in the younger age groups, 20-24-year-olds have the highest rate of knee injury. For example, this group was approximately 1.4 times more likely to suffer an ankle or knee injury compared to the younger 10-14-year-olds in 2016/17. At the age of 20+ years, many netballers in NZ stop playing structured competitive games and instead participate in more unstructured social netball competitions. The unstructured nature of this form of netball can mean players are more likely to forgo training and warm-up preparation. Several studies indicate injuries are more likely to occur during competition, especially in those that are playing at a lower-skill level (Hopper et al., 1995; Langeveld et al., 2012). The 20-24-year-old group may also have suffered previous injuries when they were younger, placing them at greater risk of injury in their present season (Mather et al., 2013). The reasons above may in-part explain the higher rate of injury amongst this age group, it would seem prudent for a national IPP to also target this group for education on conditioning and preparing their bodies for game demands (King et al., 2019).

Another reason 20-24-year-olds may be an important group to consider, is that they create the largest financial burden to ACC, for example they cost $182,406/1000 members in 2017 for all lower-extremity injuries. This is compared to 15-19-year-olds (cost = $93,731/1000 members) and 10-14-year-olds (cost = $21,880/1000 members). This is concurrent with other national scale epidemiological studies, which indicated knee injuries in 20-24-years-olds are most costly to national insurance companies (Flood & Harrison, 2009; King et al., 2019). Cost data from ACC however can be misleading, as it includes reimbursements for vocation time lost to injury. The 20-24-year-olds understandably have higher costs associated with injury, as they are more likely to be employed. The 15-19-year-olds also show high costs, have a greater injury count and likely longer consequence of future burden due to comorbidity (Mather et al., 2013). The 15-19-year-olds may therefore continue to be the greatest overall tax on the ACC system. So, continued focus on reducing injury in youth/adolescent players must remain a priority of any netball IPP, but given ACC's motivation to limit costs the 20-24-year-old audience is also essential.

A typical NZ netball season starts in March for franchise professional groups and April/May for school and recreational club teams, largely finishing in October. Our analysis of data across seasons indicates the start of the season between March-May has the highest incidence of injury for the youth/adolescent groups. This is not unexpected, as during this period many school age students are undertaking multiple team selection trials and games for club, school and representative netball teams. Many players may have gone from not playing or training for netball due to participation in other sports codes or being out of season, to high intensity game play in the hopes of selection in one or more teams. There then appears to be a drop-in injury count after May, when regular season game play is still high, but players would now be placed in their respective teams and selection trialling has stopped. These findings infer a lack of specific physical preparation for the netball season and a sudden spike in game play for selection may be a risk for youth players in netball. Spikes in acute high intensity workload, such as tournaments or when trialling for several teams have been shown to increase injury risk, due largely to increased exposure of the player to game fatigue and competition stress conditions (Blagrove et al., 2017; Hopper et al., 1995; Talpey, 2015). IPPs should therefore put some emphasis on educating players and schools on preparing for the season and/or reducing the spikes in load caused by trialling (Hopper et al., 2017; Thomas et al., 2017b). Encouraging schools to hire qualified strength and conditioning coaches, to create pre-season injury prevention protective strength, could also be beneficial to improving endurance, landing ability and protection of at-risk joints (Blagrove et al., 2017; Lloyd et al., 2014; Thomas et al., 2017b). A national IPP should follow suit by offering education and resources around pre-season conditioning programs to increase strength and improve landing ability, as these have been shown to reduce injury risk in youth sports (Lloyd et al., 2014; McCambridge & Stricker, 2008).

The second spike in injury counts occurred when training typically increases for national intermediate and secondary school tournaments. Research suggests injuries are more frequent during competition and at the end of the season, when fatigue can cause poorer landing, movement technique and performance, due to tiring stabilising muscles of the lower-limb, reduced core postural control and concentration (Ferreira & Spamer, 2010; Hopper et al., 1995; Talpey, 2015). Studies in youth basketball support these findings, showing high volumes of competition in a short-period of time (Talpey, 2015) and fatigue at the end of a season, when training and game time is overloaded can also increase injury (Caparrós et al., 2016). An increase in injuries during August near the end of the season when tournaments with high game-hours are prevalent, may be expected. Based on these findings it could be beneficial for NNZ to review the design of their season and consider spreading out national tournaments, rather than clustering them at the end of the season, when players may be at the highest point of seasonal fatigue. Changing the NNZ seasonal program or policies to reduce high peaks in gameplay, either from selection or tournaments, would appear a crucial measure for reducing injury in youth netball. This is particularly the case for 10-14-year-old intermediate school age players, who consistently demonstrate injury counts above the acceptable upper-control line.

Though the ACC system offers one of the more robust sources of data for an epidemiological study, it still has some inherent limitations. One of these limitations is the effect policy change can have on collection and therefore count of injuries. In 2013 an ACC policy changed how sports injuries were recorded, making it a requirement to identify in which sport the injury occurred during diagnosis. Therefore, a greater number of injuries were likely attributed to netball when previously they hadn't been, potentially contributing to the increase in injury counts seen in this dataset between 2013-2015. Similarly, it is believed that there has been an increase in service providers over the last decade and therefore more clinicians accessible to the public to diagnose injury claims, possibly influencing injury counts in most age groups (Fulcher et al., 2018; King et al., 2019). Finally, due to the confidential nature of this dataset, there was no way to account for multiple injury claims by an individual within the year. Multiple claims by one individual may therefore be present in the dataset, which may cause a small effect to the rate of injury. In the instance of such a large dataset, this small occurrence will likely only have a minimal effect to the data but, remains a limitation.

This research captured ACC data for netball ankle and knee injuries across the nation, including most minor, moderate and severe injuries. However, data gathered through the ACC system is not fully reflective of total incidence of injuries, as it excludes those who have failed to make an injury entitlement claim (Lythe & Norton, 1992). One such instance of unreported injury is for overuse or 'growth related' injuries, which may not be claimed through ACC. Previous research suggests youths overloading, through increased intensity of training or volume of competition are at greater risk of overuse injuries (Blagrove et al., 2017; DiFiori et al., 2014). Reportedly overuse injuries in youths can account for up to 53% of all sports related youth injuries (Brenner, 2007). This suggests that this research dataset has likely omitted a proportion of injuries present in the 10-19-year-old age group and although injury count is high, it may be underestimated.

A strength of this paper was utilisation of affiliated member numbers to calculate rate of injury, allowing a more valid comparison of injury risk between groups and years. Although there are limitations in the accuracy of these affiliation numbers, they remain the most effective denominator for the netball population in NZ at present. When compared to previous epidemiological studies, this research was also able to determine an effect of injury seasonally over the 10-years. This has allowed us to make comment on the national system for competition. In this regard it is the only paper of its kind to report epidemiological data nationally in this manner.

Conclusion

Netball ankle and knee injuries have increased over the last 10 years with the biggest increase in younger players (10-19 years). Injuries in the 20-24-year age group have been more stable but still represent the highest cost to ACC and older players continue to have a higher rate of injuries than younger players (10-14 years). Seasonal data highlighted spikes in injury in the younger age groups likely associated with intense periods of trialling and tournament play that could potentially be mitigated via changes to the structure of the season. These findings should assist Netball NZ when planning the future delivery of injury prevention strategies.

Practical Implications

- ACC, NNZ and netball communities should continue to focus injury prevention programs on younger players (10-19 years), as they have experienced the largest increase in injuries over the last 10 years. These programs may benefit from continued education emphasising good landing mechanism and movement control, as well as physical loading hours on the player.

- Injuries in all age groups have been stable or reducing since 2015. This may be in part due to the introduction of a national IPP, continuation of this program and research determining its success would be favourable.

- Injury rates in 20-24-year-old players have remained more stable but continue to have the highest rate of ankle and knee injury at present. Attempts should be made to access their more unstructured netball competitions to reduce injury. With a focus on strength and movement preparation for the game demands.

- There are seasonal injury spikes in the 10-19-year-old players coinciding with increases in tournament play and prevention strategies focusing on potentially reducing hours of competition play and physical preparation for season start, are needed.

CHAPTER FOUR: A SYSTEMATIC VIDEO ANALYSIS OF 21 ANTERIOR CRUCIATE LIGAMENT INJURIES IN ELITE NETBALL PLAYERS DURING GAMES.

Prelude

The findings of the ten-year review of netball injuries reported in *chapter three* clearly identified knee injuries as a significant problem in netball. Similarly, earlier reviews of the literature by the NIPP collaborative group (as recommended in *chapter two*) clearly identifies knee and particularly ACL injuries as a significant concern. It seemed prudent therefore to take a greater look at the mechanism and player behaviours behind acute ACL injuries seen during game play. The hopes being that coachable tips on reducing ACL injury risk could be gained from this research, then integrated and trialled in the educational workshops delivered in the warm-up intervention studies seen in c*hapters five & six*. Eventually these coaching tips will also be integrated into the content design of several other educational workshops within the NIPP.

This chapter comprises the following paper currently in review with Sports Biomechanics:

Belcher, S., Whatman, C. & Brughelli, M. (2021). A systematic video analysis of 21 anterior cruciate ligament injuries in elite netball players during games. *Sports Biomechanics* (In Review)

Abstract

This systematic video analysis of 21 anterior cruciate ligament (ACL) injuries sustained by elite-level netball players during televised games, describes the situation, movement pattern and player behaviour, providing insight regarding the injury mechanism. Seventeen of the ACL injuries occurred from jump-landing actions and only two from cutting manoeuvres. A common scenario was identified for 10 players. In this scenario players were decelerating rapidly after jumping to receive a high pass, utilising a double-footed landing with a wide base of support (WBOS). Deceleration appeared to be applied predominantly via the injured leg with the knee extended and foot planted. Often the players were unbalanced on landing with their centre of mass (COM) too posterior. ACL injury risk was further exacerbated by a counter action-reaction torque, with the head being turned away from the injured limb. A further compressive force was likely placed on the lateral aspect of the knee by bringing the ball from a high position to low at the estimated time of injury. Players may benefit from landing technique training programmes that encourage shoulder-width foot landings, with $\geq 30^{o}$ knee flexion, a small amount of plantar-flexion and their COM over their toes. Incorporating challenges to players balance and ability to cope with perturbation, may also be beneficial. Training programmes should include instruction on securing the ball in a safe neutral chest position after receiving a pass and bringing their whole body around during landing into the direction of their next pass, rather than simply turning their head to look.

Introduction

Netball is a very popular sport across the world, particularly amongst the commonwealth countries (Fox et al., 2013). Unlike many court-based sports, netball has strict rules on footwork, requiring players take no-more than one and half additional steps after receiving the ball (Netball New Zealand, 2019). Players must also remain within restricted areas of the court, dependent on the position they are playing and whilst defending an opponent must stay at least 90 cm from the opposing player (Hopper et al., 2017).

To avoid violating the footwork and court restriction rules players must perform a high frequency of jumping, change of direction (COD) or sudden deceleration tasks (Ferreira & Spamer, 2010; Fox et al., 2013). Poor technique during these movements, particularly landing from jumps, is thought to contribute to the high rate of lower extremity injury in netball (Boden et al., 2010; Downs et al., 2021; Stuelcken et al., 2016). A recent 10 year review of knee and ankle injuries in netball confirmed knee injuries are the most costly (Belcher et al., 2020) and Anterior Cruciate Ligament (ACL) rupture is reported to be the most serious in-terms of time lost to play (Ferreira & Spamer, 2010; Flood & Harrison, 2009; Hopper et al., 1995; King et al., 2019). The repeated high impact loading created from landing motions, likely contributes to the incidence of overuse and acute injuries in high-performance and recreational players alike (Hopper et al., 1995; Renstrom et al., 2008). It is suspected that some netball players retire early from the sport, because of serious knee injuries (Hopper et al., 1995) and in this regard ACL injury is of particular concern for netball players (Downs et al., 2021; King et al., 2019). There is evidence to indicate ACL injury can cause emotional distress, hinder academic and athletic achievement (Morrey, Stuart, Smith, & Wiese-Bjornstal, 1999) and lead to associated menisci damage with increased risk of osteoarthritis (Lohmander et al., 2007).

Due to the costs and long-term consequences, it is important to understand the mechanism, behaviours and events surrounding the occurrence of ACL injury in netball. Understanding injury mechanisms is an integral step in injury prevention research (Hewett et al., 2010). Video analysis allows for assessment of real injury scenarios and therefore sport-specific injury mechanisms, reducing the limitations associated with player and/or coach recall of injury event (Bere et al., 2011; Krosshaug et al., 2007). As well as the ability to investigate joint biomechanics and loading patterns that lead to injury, video analysis allows for the assessment of playing situation (players movements before and at the point of injury) and player behaviour (Montgomery et al., 2018). Several studies have successfully used video analysis to investigate ACL injury mechanisms across a range of sports including Skiing (Bere et al., 2011), Australian Rules football (Cochrane et al., 2007), basketball (Krosshaug et al., 2007), handball (Olsen et al., 2004), rugby (Montgomery et al., 2018) and netball (Stuelcken et al., 2016).

Historically research exploring the mechanism of ACL injury has largely focussed on lower-limb biomechanics and in particular knee position (extended [stiff] or flexed [compliant], varus or valgus) (Ferreira & Spamer, 2010; Hewett et al., 2010; Weiss & Whatman, 2015). More recently research investigating ACL injury mechanisms has shifted focus to the effect trunk position can have on landing technique, COD and the subsequent influence on knee injury (Davis et al., 2019; Dempsey, Elliott, Munro, Steele, & Lloyd, 2012; Hewett et al., 2009). A particular focus has been the negative effect of poor trunk stabilisation and subsequent lateral trunk flexion on ACL injury (Hewett et al., 2009; Hinshaw et al., 2019; Waldén et al., 2015; Zazulak et al., 2007). Another recent theme in several studies has been the effect perturbation in the air has on landing mechanics and knee moments (Della Villa et al., 2020; Song et al., 2021; Yom et al., 2014). The belief being that perturbation in mid-flight can increase the chance of lateral trunk flexion and/or extension, reduce balance on landing and the subsequent increased risk of apparent valgus collapse (Della Villa et al., 2020; Song et al., 2021; Yom et al., 2014).

Previous research has explored how differing biomechanical actions contribute to the mechanism of ACL injury in a variety of teams (Koga et al., 2010; Krosshaug et al., 2007; Montgomery et al., 2018; Olsen et al., 2004). Although ACL injuries are acknowledged as a significant concern in netball, there is very little research into the mechanism of knee injury during game play (M. Stuelcken et al., 2016). Likewise, there is a paucity of studies examining the relationship of head position in relation to the rest of the body mechanics or the finishing position of the upper limbs after receiving a pass on ACL injury mechanism. It would seem prudent to assess the effect of head and upper limb position on knee injury, as they are clearly a factor in a competitive ball sport where you must receive a ball and look to identify other players or space in the playing field. Understanding the contribution of player movement behaviours (head position and where the ball is placed) and/or external environmental factors (contact/perturbation) on knee injury risk during netball, will help develop future IPP strategies. Specifically, it can be used to guide the content and implementation of national IPPs, such as 'NetballSmart' (https://www.netballsmart.co.nz). Therefore, the purpose of this study was to undertake a systematic video analysis of in-game ACL injuries in elite netball players, to describe player behaviour, game situation and patterns of movement that potentially contribute to the injury mechanism.

Method

This was a cross-sectional observation study. A search of the media archives from Netball New Zealand (NNZ), for broadcasted ACL injuries between January 2008 and October 2019 in either the Australia and New Zealand (ANZ) premiership or international netball competitions identified 21 cases of ACL rupture. Originally 28 cases were identified but seven were excluded from further consideration because the injury (1) occurred in training, (2) occurred during a non-televised game or (3) was a tear to a previously reconstructed ACL. ACL injuries that occurred in players who had a previous contralateral ACL reconstruction were included in this study and the information described in the results. This study was granted an exemption from the need for ethics approval as all video footage is publicly available and no personal player information was accessed. The video footage was converted into .mov digital files. The resolution of the video footage was broadcast quality at either high definition (1280x720 pixels) or standard definition (960-1024x540-576 pixels). All 21 injury cases had a minimum of two camera angles, with most having at least three angles. The footage was viewed using Kinovea© (www.kinovea.org, v. 0.8.15), a free 2D motion analysis software that enables the establishment of kinematic parameters, differing playback speeds and the ability to analyse footage frame-by-frame.

A group of experts including two accredited physiotherapists (Physiotherapy New Zealand), one orthopaedic surgeon with extensive experience of ACL injury, one retired international player/high-level netball coach and one strength and conditioning coach working in high performance netball met and viewed all videos in real time and frame-by-frame to determine an estimated index frame (IF). The IF was defined as the time when the ACL appears to have ruptured (seen as forward translation of the tibia under body weight or clinically reasoned by the expert group). The time five seconds prior to and after the IF was then identified. This created a 10-second index time interval, which allowed for observational analysis of the investigated critical features surrounding the injury (Montgomery et al., 2018; Stuelcken et al., 2016). A consensus (defined as four of the five experts agreeing) regarding the IF for all injury cases was agreed before analysis occurred.

The agreed critical features for analysis were determined by the group of experts following (1) review of previous variables used in similar studies in netball and other sports (Krosshaug et al., 2007; Montgomery et al., 2018; Olsen et al., 2004; Stuelcken et al., 2016; Waldén et al., 2015) (2) review of performance analysis studies in netball (Davidson & Trewartha, 2008; Fox et al., 2013), and (3) consultation with high-performance NNZ staff . The critical features included information on the game and environmental external situation (e.g., contact or not with other players) and the player's movement during the 10-second index time interval (e.g. running on to a ball, landing). It also included the player's movement behaviour (e.g., head position or where they moved the ball). A full list of all critical features assessed is provided in Table 2. Visual inspection of knee joint flexion angles was in line with previous video analysis protocols (Cochrane et al., 2007; Krosshaug et al., 2007; Montgomery et al., 2018), with the additional use of the Kinovea© angle drawing tool to offer extra guidance (Adnan et al., 2018). Joint flexion angles were used to signify if the knee was in a relatively extended position ($\leq 30^{o}$ flexion) or flexed ($> 30^{o}$ flexion) during the IF moment. These parameters for knee flexion were based on previous research indicating $<30^{o}$ flexion increases injury risk and agreement amongst the expert observational group (Hewett et al., 2010; Koga et al., 2010;

Krosshaug et al., 2007). All five members of the expert observation group viewed the videos individually and sent their results to a single reviewer to collate. If a consensus (defined as four of the five experts agreeing) was not reached for a particular critical feature, the video was re-analysed by the full expert group and discussed until a consensus was reached. Microsoft Excel spreadsheets from Windows (Microsoft Excel 2016, Redmond, Washington, USA) were used to store and analyse data.

Results

Inspection of **Table 1 s**hows 21 ACL cases, 12 (57%) of which involved the left knee and nine (43%) the right. The most frequently injured position was wing attack (seven, cases), followed by centre (five cases), goal shooter and wing defence (three cases), goal attack (2, cases) and goal defence (one case). In summary 12 cases occurred in the attacking third, six cases in the centre and three in the defensive third of the court. In 16 cases (77%) the injured player was receiving an offensive pass with their team in possession of the ball. Only three cases (14%) occurred whilst the player was defending, and there were two cases where both teams were chasing a loose ball in open play. Of the 16 cases involving offensive passes, nine (56%) started with the ball in flight from behind the player, before being caught in a forward-facing position by the player. In two cases the ball came from behind the player and the player was either competing for a loose ball or defending the centre pass. In 16 cases injury occurred whilst the ball was in play and three cases were during a restart or centre pass. More injuries occurred during the first quarter of the game (eight cases), followed by the third quarter (five cases) and four cases equally in the second and third quarters. There were only three cases where the player's contralateral knee had undergone ACL reconstruction surgery prior to the current injury occurring.

In 17 (81%) cases the injured player was landing from a jump, 13 of which were categorised as double-leg and four as single-leg landings (where the player failed to place their second foot down, before the next play was made). In all but three of these instances the player was performing a medium-high intensity run, prior to take-off and had to rapidly decelerate due to some external factor (e.g., opposition player). Of the 14 cases where the player ran at medium-high intensity before jumping, 11 of the players predominately used their injured side to decelerate their movement. Regardless of whether the injury occurred due to a jump action or another movement, 17 of the players chose their injured leg to create a braking force to stop their momentum and in 16 cases this was done with an extended knee position. Other common critical features of lower-limb mechanics seen at the time of player's injury were their centre of mass (COM) being too posterior (11 cases), a wide base of support (WBOS) (17 cases), the knee at or close to being fully extended (19 cases) and all 21 cases had their foot fully planted at time of injury. In only two cases was the player in an apparent valgus knee position before the injury occurred. More commonly (seven cases) players had some degree of knee valgus collapse at the time of injury and most frequently (11 cases) the knee only collapsed after the injury occurred. There were only seven cases where the player placed their injured leg down first. In most instances (14 cases) it was the second leg to touch down when stepping or landing from a jump. Finally, only two cases resulted from performing a side-step or cutting type movement.

Critical features frequently observed that affected the upper body included five cases where the player had to overreach either for a poor pass from their teammate or four cases in which they were attempting to intercept the ball. Another common factor was the end position of the ball at the time of injury, after collecting an offensive pass in the air. In 12 cases, the injured player took the ball high in the air before bringing the ball either low (pelvis level or below) and over the injured limb (eight cases), low and central (three cases) or low to the uninjured side (one case). This contrasts with only three cases where the player brought the ball to the standard central chest position after receiving the pass. The most recurrently observed critical upper-body feature at time of injury was the players head position, which in 16 cases was turned 45-90^{o} away from their injured limb. Trunk position at the time of injury seemed to be less critical to mechanism of injury, with only four cases where the trunk was rotated towards the side of the injured knee, five cases where the trunk was laterally flexed towards the injured side and one case where the trunk was excessively flexed forwards. Of note there were seven cases where a player's upper body was contacted by the opposition prior too, during a jump or whilst grounded.

A summary of the critical observable features described above for all 21 cases and their link to ACL injury risk factors from the literature, is shown in **Table 2**. After analysis of these findings by the expert reviewer group, a common injury mechanism scenario was identified for nearly half the players. These 10 players are highlighted in **Table 2.** The 10 players all appeared to be running at medium-high intensity, before taking-off to jump and receive a pass from a teammate. They then decelerated rapidly from the jump and generally seemed to achieve this with a double footed, WBOS landing, breaking their force through their injured leg by bringing it into an extended knee position and planting their foot into dorsi-flexion. In nine of these cases the player landed with their uninjured foot first before bringing the injured limb out into extension to break the movement. All 10 players also appeared to be slightly unstable on their landing, due to their COM being too posterior. In eight of the cases the players had received the ball high in the air or out to the side, then on landing opted to bring the ball low and over their injured knee (six cases) or low and central (two cases). At the time of injury nine players had also turned their head (looking for their next pass), 45-90^{o} away from their injured knee. An example of this scenario can be seen in the collected image sequences in **Figure 1**.

Table 1. Descriptive information on game situation and the player's movement surrounding the injury event.

Player video no.	1	2	3	4	5	6	7	8	9	10	11	12	13	4	15	16	17	18	19	20	21
Player position	GS	GS	C	GS	WA	GA	WA	WD	C	WD	GD	WA	C	C	WD	C	WA	WA	WA	GA	WA
Side injured	L	R	L	R	L	R	R	L	R	L	L	L	L	L	L	R	R	R	L	L	L
Court area	A	A	A	A	CC	A	A	CC	A	CC	D	A	A	A	D	D	CC	CC	CC	A	A
Game Quarter	Q1	Q3	Q1	Q3	Q1	Q2	Q1	Q4	Q2	Q2	Q3	Q1	Q1	Q3	Q1	Q1	Q4	Q2	Q4	Q4	Q3
Ball in play (P), loose (L) or from a start (S)	P	P	P	P	S	P	P	P	L	P	P	P	P	P	S	P	L	P	S	P	P
Receiving a pass	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	N	N	N	N	Y	Y
Defending the ball	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	Y	Y	Y	Y	N	N
Ball coming from behind player into forwards	Y	N	Y	N	N	Y	N	N	Y	N	Y	Y	Y	Y	Y	N	N	N	Y	Y	Y
No. of camera angles	3	2	3	5	3	2	2	2	3	2	3	3	3	3	2	3	2	3	3	3	3
Contralateral ACL	N	N	Y	N	N	N	Y	N	N	N	N	N	N	N	N	N	Y	N	N	N	N
Quality of video	St	H	H	H	H	St	H	H	St	H	H	H	H	St	H	H	H	H	St	H	H

N= No; Y=Yes; GS= Goal Shooter; C= Centre; WA= Wing Attack; GA= Goal Attack; WD= Wing Defence; GD= Goal Defence; A= Attack Court; CC= Centre court; D= Defence court; St= Standard-definition (960-1024x540-576 pixels); High-definition (01280x720 pixels)

Table 2: Critical observable features and links to injury risk factors from the literature.

Critical observable features	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	Total
1. Running at medium-high intensity[b,g,j,k,m,q]			✓		✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	18
2. Injury occurred performing a side-step cutting maneuver[a,b,g,h,i,j,k,m,n,o,q,r]										✓	✓											2
3. Injury occurred landing from a jump [a,b,d,h,i,j,l,m,n,o,p,q,s]	✓		✓	✓	✓	✓	✓	✓	✓			✓	✓	✓	✓	✓		✓	✓	✓	✓	17
4. Injury occurred whilst rapidly decelerating [a,e,g,j,m,n,p,q]			✓	✓	✓	✓		✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	17
5. Player's centre of mass was too **posterior** [c,e,g,j,n,o,p,q,r,s]			✓	✓	✓	✓	✓	✓	✓	✓	✓			✓	✓					✓	✓	11
6. Players centre of mass/weight was too **anterior** [c,e,j,n,o,p,q,r]		✓																				1
7. Player was contacted in the air or on the ground when injury occurs[c,i,n,q,s]		✓			✓								✓			✓	✓	✓	✓			7
8. Single leg landing or position [a,f,h,i,m]	✓															✓		✓	✓			4
9. Double leg landing or position [a,f,i,m,q]		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓			✓	✓	17
10. Player overreaching to receive a pass or collect a ball[c,d,n,q]		✓		✓					✓	✓		✓				✓	✓	✓	✓			9
11. The first leg to make contact was the injured side [d,e,j,q,r]	✓	✓								✓					✓	✓		✓	✓			7
12. Predominate breaking force was on the injured leg [a,b,e,j,k,m,n,q,r]	✓	✓		✓	✓		✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	17
13. Injured foot was planted flat[a,j,k,n,p,q,r]	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	21
14. Player incurred contact prior to jump or side-step [f,i,n,q,r]		✓														✓	✓	✓	✓			5
15. Player landed with a wide base of support/feet far apart[d,e,i,n]		✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			✓	✓	18
16. Trunk rotated (transverse plane) **towards** the side of the injured knee at time of injury[e,f,j,n,q,r]		✓						✓				✓				✓						4

17. Trunk laterally flexed (frontal plane) **towards** the side of the injured knee at time of injury[e,f,j,n,q]	✓															✓	✓	✓	✓			5
18. Trunk excessively **forward flexed** (sagittal plane) at time of injury[c,e,j]		✓																				1
19. Injured knee at or close to full extension when injury occurs[a,b,c,e,i,j,k,m,n,p,q,r]	✓		✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	19
20. a) Apparent valgus collapse **before** injury occurs [e,g,h,i,l,q,r]											✓				✓							2
20. b) Apparent valgus collapse **at time of** injury [e,g,h,i,l,q,r]				✓							✓	✓			✓			✓	✓	✓		7
20. c) Apparent valgus collapse **after** injury occurs [e,g,h,i,l]	✓		✓		✓	✓		✓	✓	✓			✓			✓	✓				✓	11
21. a) Ball position on completion of movement is **low to the injured side**[d]		✓		✓	✓	✓		✓	✓			✓									✓	8
21. b) Ball position on completion of movement is **low and central[d]**			✓										✓	✓								3
21. c) Ball position on completion of movement **is low to the uninjured side[d]**																	✓					1
21. d) Ball position on completion of movement is at **chest height[d]**															✓			✓		✓		3
22. At time of injury, head position is turned 45-90^{o} away from the injured limb.	✓				✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓		✓	✓	✓	**16**

Notes: [a]Boden et al., 2010; [b]Cochrane et al., 2007; [c]Davis et al., 2019; [d]Dempsey et al., 2012; [e]Hewett et al., 2010; [f]Hinshaw et al., 2019; [g]Johnston et al., 2018; [h]Koga et al., 2010; [i]Krosshaug er al., 2007b; [j]Mehl et al., 2018; [k]Montgomery et al., 2018; [l]Mullally et al., 2021; [m]Olsen et al., 2004; [n]Renstrom et al., 2008; [o]Song et al., 2021; [p]Sheehan etal., 2012; [q]Steucklen etal., 2015; [r]Waldén et al.,2015; [s]Yom et al., 2014.

Highlighted columns represent the 10 players identified by the expert reviewer group with a common injury mechanism scenario as seen in Figure 1.

Figure 1. (a): Running at medium/high intensity to receive pass. (b): Player performs a jump reaching high to receive the pass. (c): Player is bringing the ball down, their COM is too posterior, preparing for rapid deceleration and turning their head 45-90° away from their injured limb, look towards their teammate for the next pass. (d): Player has landed with a WBOS, with their COM too posterior, their injured right knee is the second to touch-down and has been used as the predominate breaking force, with an extended knee and their foot planted flat. They have kept their head rotated 45-90° away from their trunk position and the injured side, bringing the ball low over there injured knee.

Discussion

Netball participants at both a high-performance and recreational level are susceptible to ACL injuries (Downs et al., 2021; Flood & Harrison, 2009; King et al., 2019). Stuelcken et al. (2016), undertook the first systematic video analysis study exploring the mechanism of ACL injury in elite netball players. The current study has expanded on the findings of that research and recognised undiscussed potential risk factors (turning the head too look in-court away from the injured leg and bringing the ball low at time of injury). These new findings could be used to inform the development and implementation of neuromuscular training (NMT) sessions, coach/player injury prevention education and screening tools.

In most of the cases (17) the player was landing from a jump, which is in keeping with the findings of Stuelcken et al. (2016). Of those 17 cases, 14 were jumping to receive an offensive pass, but only six injuries occurred due to overreaching for a poor-quality pass. It would seem acceptable to suggest that though receiving a pass is a high-risk manoeuvre it is not necessarily due to poor quality passing, but more likely how the player chooses to land after receiving the ball that is the greater risk to ACL injury. As jumping to receive a pass is a frequently performed movement during netball (Davidson & Trewartha, 2008; Ferreira & Spamer, 2010; Fox et al., 2013), there must have been something atypical about these landings that contributed to the ACL injury.

In 14 of the landing cases, the player had to decelerate rapidly from a medium-high intensity run. There are several reasons a player must decelerate fast during netball. Sometimes it is to avoid collision with an opposing player, but most often it is to avoid violating footwork and court restriction rules. (Ferreira & Spamer, 2010; Fox et al., 2013; Lee Herrington, 2010) Frequently in this study players appeared to choose a similar method to slow their landing, performing a double footed landing with a WBOS (11 cases) and leaning their COM back (nine Cases). They also choose to control the deceleration of this double leg landing position by placing their injured leg out into an extended knee and their foot planted, with what appears to be most of their weight on the injured limb (12 cases). There has been much discussion in the literature highlighting an extended knee and planted foot as a high-risk position for ACL injury, either in jump-landing or cutting manoeuvre's (Boden et al., 2010; Mehl et al., 2018; Montgomery et al., 2018; Renstrom et al., 2008; Stuelcken et al., 2016). When a player attempts to slow their horizontal momentum a large posterior (braking) ground reaction force (GRF) is required. Often females will counterbalance this posterior braking force by creating an internal knee extension moment, often through contraction of the quadriceps femoris muscle group (Olsen et al., 2004). Contraction of this muscle group creates a strain on the ACL, by producing an anterior shear force on the proximal end of the tibia via the patella tendon, which is further exacerbated when the knee is in an extended position (Dai, Herman, Liu, Garrett, & Yu, 2012; Hewett et al., 2010). An extended knee position with a planted or anchored foot on the court surface, will also reduce ankle mobility and potentially force the knee to become the mobile joint in the lower-limb chain, increasing the risk of injury to the stabilising structures of the knee (Boden et al., 2010; Mehl et al., 2018; Montgomery et al., 2018). The decision to land leaning back with a WBOS may be to gain a stable position without violating the footwork rule when decelerating (Boden et al., 2010; Stuelcken et al., 2016). Though landing in this manner may increase the risk of ACL injury, comparatively a forefoot landing with a narrow base and the ankle plantarflexed can increase the potential for ankle sprain due to pressure on the lateral aspect of the foot-ankle (Wright, Neptune, van den Bogert, & Nigg, 2000). Therefore, training netball players to land with their feet shoulder-width apart and their COM balanced is important. Finally, only two injury cases were identified as coming from a side-stepping COD or cutting manoeuvre rather than jumping, which is in accordance with Stuelcken et al. (2016) findings in netball and (Krosshaug et al., 2007), findings in female basketball players. The implications of these studies are that although side-stepping or cutting has been identified as the most common offensive manoeuvre in elite netball, it is perhaps not a high-risk action (Fox et al., 2013). Whether this is the case in recreational netball is unknown, as little literature exists that investigates mechanisms of ACL injury at this player level and there are no systematic video analysis studies. However, given the evidence supporting landing as the most high-risk manoeuvre, IPPs would benefit from focusing on good landing technique. Coaches, physical education teachers, sports and exercise professionals should instruct their players to control deceleration from jumping movements, aiming to land with feet shoulder width apart and knees in > 30^{o} flexion. Players should try to land with small amounts of plantar flexion and their COM centered over their toes (Boden et al., 2010; Hopper et al., 2017; Wright et al., 2000).

It is believed a WBOS landing without compensatory knee flexion and external rotation of the foot can create greater internal hip, knee rotation and abduction force, increasing the risk of secondary valgus collapse (Dai et al., 2012; Davidson & Trewartha, 2008; Hewett et al., 2010; Hopper et al., 2017). Of the 14 cases in the current study where a player was landing from a jump with a WBOS, nine did not collapse into valgus until after the injury occurred, three cases at the time of injury and only one before. This is inconsistent with previous systematic video analysis ACL injury research, which suggested apparent valgus was most common before or at the time of injury in handball, basketball (Krosshaug et al., 2007; Olsen et al., 2004) and netball (Stuelcken et al., 2016). However, studies investigating ACL injury mechanism have begun to acknowledge that perhaps their initial observations were incorrect and the apparent knee valgus collapse may have been a result of ACL injury rather than a cause (Dai et al., 2012; Quatman, Quatman-Yates, & Hewett, 2010).

Assessing apparent valgus collapse is considered difficult through observation alone and particularly when only seeing one camera view or when the frontal plane is obscured by the players position (Bere et al., 2011; Krosshaug et al., 2007; Waldén et al., 2015). However, in the current study 100% of the ACL incidents had at least two camera angles, which is more than any previous studies of this type reported (26-75%) (Bere et al., 2011; Krosshaug et al., 2007; Stuelcken et al., 2016; Waldén et al., 2015). This strengthens the current study's findings that apparent valgus collapse was often more likely a result of ACL injury rather than necessarily the cause. Additionally, the frontal plane abduction of the knee itself may not actually be the initiating factor in "valgus collapse' (Dai et al., 2012; Quatman et al., 2010). Instead, it may be the last motion in a chain reaction, where first the hip internally rotates and then to balance this motion the tibia externally rotates in relation to the femur. This may result in an elongation of the ACL and impingement against the lateral aspect of the condylar notch, increasing injury risk (Dai et al., 2012; Quatman et al., 2010). Although the evidence for these mechanisms comes from basketball rather than netball there is perhaps an opportunity for IPP implementors in netball to explore other risk factors as their focus of rehabilitation or injury prevention. Instructions to reduce 'valgus collapse' or colloquially 'knocking knees' given by IPP implementors, should not be the initial focus of improved landing technique. It may be better to focus on reducing the WBOS landing while increasing knee flexion. Strengthening the hip and pelvis musculature, may also help reduce internal rotation and adduction at the hip, which is often a contributor to knee valgus collapse (Mehl et al., 2018; Michaelidis & Koumantakis, 2014; Renstrom et al., 2008).

Another biomechanical risk factor for ACL injury discussed in the literature, is the effect of trunk position (Song et al., 2021; Stuelcken et al., 2016; Zazulak et al., 2007). It is believed lateral trunk flexion towards the injured side, can increase abduction forces on the lateral aspect of the knee, increasing pressure through the ACL (Della Villa et al., 2020; Hewett et al., 2009; Song et al., 2021). Additionally, rotation of the trunk away from the injured side may transfer force through the hip and pelvis, possibly increasing hip internal rotation and adduction (Hewett et al., 2009; Quatman et al., 2010). Results of the current study contradict much of this literature, in that no players showed signs of trunk rotation away from the injured side at the time of injury and only four cases involved rotation towards the injured knee. Like previous studies there was five cases involving lateral flexion of the trunk towards the injured knee. Overall, there was significantly less injury cases (39%) where some form of altered trunk alignment occurred on landing compared to Stuelcken et al. (2016) who reported trunk alignment contributing to 88% of their injury cases in a similar group of elite netballers. Though, the current study did not report many signs of altered trunk position at time of injury, we did see 16 cases where the player had turned their head 45-90^{o} away from the injured knee. Head position at the time of injury has not been previously recorded in any of the ACL injury video analysis research. Theoretically some of the cases of trunk rotation away from the injured side may have been rotation of the head rather than the trunk (Montgomery et al., 2018; Stuelcken et al., 2016). This is evident within this study, as many of the injured players followed a scenario where they turned their head initially before the apparent ACL tear occurred and then after injury their trunk position followed the rotational direction of their head. Whilst netball rules stipulate that players are allowed 3seconds to hold the ball before it must be passed or shot, at elite level the average time it takes to receive and distribute the ball is 1-2seconds (Fox et al., 2013). Being able to move the ball quickly between players is likely an important tactic for success, but potentially pressures the player to pre-empt their next play by looking around before they have been able to completely bring their body position around and land safely. Hypothetically, focusing on looking for a pass without completing the turn through the air to land correctly, could place the player in an unbalanced position. It may also create a counter action-reaction torque from the head turning in the opposite direction away from the fixed extended knee (Critchley et al., 2020). There were 12 cases where a player was thrown a pass from behind and had to turn ≥180^{o} to receive the pass in-front of their original position. Therefore, coaches may benefit from instructing players to turn their body 'completely' to face the direction of their next pass rather than 'look' for their next pass, even if it increases the time taken to perform the movement (Dos'Santos, Thomas, McBurnie, Comfort, & Jones, 2021). Landing technique that encourages upper body control and bring their head position more central could possibly reduce the risk of injury and place the player in a better position to make a successful subsequent pass. Coaches should be wary of getting their players to carry-out movements focusing on optimising time performance if it places them in a high-risk injury position, especially if they lack the physical capacity (neuromuscular control) to do so (Dos'Santos et al., 2021).

Much of the research exploring the impact of unstable or altered trunk position, comes from investigating mid-flight motions (Davis et al., 2019; Hinshaw et al., 2019; Song et al., 2021). Often a player may experience trunk perturbation or contact (opposition player, ball) before, during or on landing from a jump (Song et al., 2021; Yom et al., 2014). When a player undergoes some form of trunk alteration mid-flight with/without perturbation, they tend to land in an unstable position with their weight too far back (Davis et al., 2019; Hinshaw et al., 2019). They may also show increased lateral trunk flexion or internal rotation and abduction force through the knee, increasing ACL injury risk (Stuelcken et al., 2016; Waldén et al., 2015). Contact with the trunk and/or arms contributed to more than 80% of the indirect contact near the time of ACL injuries in these studies (Della Villa et al., 2020; Koga et al., 2010; Olsen et al., 2004; Waldén et al., 2015). Within the current study there were seven cases where a player was contacted prior to jumping or side-stepping, in the air or immediately on landing. Thus, only seven individual players (33%) experienced some form of perturbation as part of the ACL injury mechanism. Stuelcken et al. (2016), reported similar findings with seven cases of perturbation occurring as part of the injury mechanism, (44% of their player cohort). Based on previous literature and the current study's findings, incorporating trunk motion and perturbation jump-landing and cutting technique training would be beneficial. Coaches should train their players to return to a protective trunk position and adopt soft landing techniques after unanticipated trunk perturbation (Song et al., 2021; Waldén et al., 2015; Zazulak et al., 2007). The role of trunk motion in ACL injury risk has highlighted the potential benefits of trunk muscle strength and activation on jump-landing and cutting mechanics. Therefore, adding core, pelvic and abdominal strengthening to NMT or IPPs could also be beneficial (Song et al., 2021; Zazulak et al., 2007).

After examination of the key observable criteria in relation to previously identified risk factors from the literature, the expert research group in this study identified 10 cases with a common set of critical features (Table. 2 and Fig 1). How some of these common critical features may contribute to ACL injury mechanism has been discussed above, but an area of little exploration is the effect the placement of the ball has on injury. In eight of the 10 scenarios the players received a pass high in the air, then on landing opted to bring the ball low and over their injured knee (six cases) or low and central (two cases). Moreover, the results of all 21 ACL injury analyses show that there were 12 cases (57%) when the ball was caught high and brought low, in comparison to the three cases (14%) where the ball was collected and brought to a stable recommended chest position. Most commonly (eight cases) the players were observed receiving the pass high and bringing the ball low and towards their injured knee. It is possible the forces created by bringing the ball down over the side of the injured knee could increase the compressive knee moments on the lateral aspect of the knee furthering the risk of ACL injury, much like the effect of lateral trunk flexion (Della Villa et al., 2020; Song et al., 2021). Dempsey et al. (2012) looked at testing controlled high ball catching motions, reporting that the peak knee valgus moments occurred when the ball was brought towards the landing leg, on single-leg landing. Bringing the ball from high in the air and down diagonally across the body on landing may also create a reaction torque through the body to the injured limb (Critchley et al., 2020). Catching skills are important in netball training and coaches may reduce the risk of ACL injury by encouraging their players to bring the ball to a stable central trunk/chest position on receiving a pass. This may not only help reduce injury risk but improve performance, by reducing the chance of the next offensive pass being intercepted due to the ball's low trajectory. The potential relationship between the environmental task (turning the head to look for a pass and ball placement), game constraints and decision-making on injury, needs further investigation.

The limitations of the current study are like others in the field, one of which is that a relatively small sample of injury cases was observed. The number of cases was however comparable to previous studies in handball (Olsen et al., 2004), skiing (Bere et al., 2011) and netball (Stuelcken et al., 2016). This study only recorded injuries that occurred during televised competitive games sustained during the ANZ Championship or NZ international netball competitions. This will naturally exclude any developmental or recreational-level players or information on injury mechanism during training scenarios. Similarly, a video-analysis method such as this can only comment on observational outcomes seen at the time of injury. We are unable to account for other intrinsic or extrinsic risk factors (fatigue, training effects) that may have had a significant effect on the injury occurring (Meeuwisse et al., 2007). The ACL injury cases were initially identified through investigating print media reports, which may have resulted in some selection bias. Finally, the exact moment when an ACL tear occurs is hard to accurately determine during video analysis and there are challenges with estimating joint angles.

Conclusion

In conclusion, most ACL injuries in the current study occurred when landing from a jump. A common scenario was identified during which players appeared to be attempting to decelerate their landing motion after receiving a ball high, utilising a double-footed and WBOS action, applying braking forces through an extended knee and flat-foot position on their injured leg. Often the players were unbalanced on landing with their COM too far back. ACL injury risk was possibly exacerbated by creating a counter action-reaction torque through the body, starting from their head turning away from the injured side and continuing through to the extended lower limb. A further compressive knee moment was likely placed on the lateral aspect of the knee by bringing the ball from a high position to a low position at the estimated time of injury. Coaches can use these findings to guide jump-land training in netball.

Practical Applications

- Coaches, sport and exercise professionals and physical education teachers should instruct their players in targeted landing technique training. Instructions should encourage controlled deceleration from jumping movements, aiming for a shoulder-width apart fore-foot landing position, > 30^{o} knees flexion and their COM centred over their toes.

- Coaches should give specific instruction on receiving the ball and then securing it in a safe close to chest position, as well as bringing their whole body around into the direction of their next pass rather than simply turning their head to look.
- Incorporating challenges to players balance and ability to cope with perturbation, may also be beneficial.
- Adding core, pelvic and abdominal strengthening to movement control NMT or IPP exercises, could be beneficial in controlling trunk motion during jump-landing and cutting mechanics.

CHAPTER FIVE: SHORT AND LONG VERSIONS OF A 12-WEEK NETBALL SPECIFIC NEUROMUSCULAR WARM-UP IMPROVES LANDING TECHNIQUE IN YOUTH NETBALLERS

Prelude

Neuromuscular training has been identified in the literature as a successful tool in the prevention of lower extremity injuries such as those common in netball. This chapter (together with *chapter six)* explores the effectiveness of the two most prominent resources in the NIPP, the NetballSmart Dynamic Warm-up (NSDW) and Power warm-up (PWU). This is another key step identified in the narrative review in *chapter two* (**Step 6**), allowing the NIPP an opportunity to evaluate the effectiveness of resources with members of their netball community. Findings can then be used to determine any adaptations or improvements that may be required for the next year of the programme. Results from *Chapter four,* together with previous research has clearly identified poor landing technique as a risk for knee injury in netball. With this in mind *chapter five* investigates the effects of the warm-ups on improving landing technique. The practical coaching implications for improving landing technique from *chapter four,* were added to the pre-intervention coaching workshops for the players and coaches. The results of *chapter three* informed the target age group for these studies.

This chapter comprises the following paper published in: Physical Therapy in Sport.

Belcher, S., Whatman, C., Brughelli, M., & Borotkanics, R. (2021) Short and long versions of a 12-week netball specific neuromuscular warm-up improves landing technique in youth netballers. *Physical Therapy in Sport, 49*:31-36.

Abstract

Objective: To investigate the efficacy of two 'NetballSmart', netball specific warm-ups in improving landing technique measures in New Zealand secondary school netball players.

Design: Cluster randomised control trial.

Participants: 77 youth participants, mean ±SD age = 15.8 ± 0.9 were recruited from secondary school netball teams.

*Setting:*12 teams from 6 schools performed either the NetballSmart Dynamic Warm-up (NSDW) (n = 37); or Power warm-up (PWU) (n = 40), three times a week for 12 weeks. All players within a school (2 teams) were assigned the same warm-up, avoiding treatment contamination.

Main outcome measures: A series of unilateral and bilateral drop vertical jumps on to a portable force plate were completed by all participants. Measures included peak vertical ground reaction force (GRF) for single-leg and bilateral landings; frontal plane projection angle (FPPA) for right and left single-leg landings and Landing error scoring system (LESS) for bilateral landings.

Paired t-tests were used to assess mean differences pre- and post-the warm-up. Generalised linear mixed effects models were developed to evaluate the effects between the NSDW and PWU groups.
Results: Significant improvements were found in all the landing technique outcome measures for both warm-up groups (ES Range- **GRF** = -0.6 to -1.1; **FPPA** =0.8 to 1.2; **LESS** = -1.6 to-3.2; $p<0.05$). Results of mixed effects models revealed that there was only a significantly greater improvement in LESS for the PWU group (ß = -0.30, p = 0.001).
Conclusion: Results show both warm-ups can improve landing technique measures in youth secondary school netball players. It is recommended that coaches should consider implementing one of the two warm-ups in their netball programmes. Their choice of warm-up will likely be dependent on their environment and time demands.
Keywords: Netball, Neuromuscular warm-up, Youth, Sport injury

Introduction

Netball is a popular sport in New Zealand (NZ), particularly amongst youth who comprise approximately 50 to 60% of affiliated members. Netball also remains the number one female sport in NZ secondary schools (Netball New Zealand, 2019). Netball requires a range of explosive anaerobic movements including repeated sprints, changes of direction (COD), cutting, jumping and landing (McManus et al., 2006; Thomas et al., 2017b). Moreover, to avoid violating the unique rule of no-stepping whilst in possession of the ball, players must rapidly decelerate during these tasks (Fox et al., 2013; McManus et al., 2006; Otago, 2004). Poor technique during these movements, particularly landing with limited knee flexion and/or valgus knee collapse, can increase risk of lower extremity injury (Bates, Ford, Myer, & Hewett, 2013; Hewett et al., 2010; Myer et al., 2009). Increased ground reaction force (GRF) when landing has also been linked to risk of lower-extremity injury due to changes in developing joints, soft-tissue and bone growth in youth, as well as reduced neuromuscular control during growth phases (Boling et al., 2010; Hopper et al., 2017; McManus et al., 2006). Whereas correct landing technique has often been described as important to reducing landing GRF and knee injury (Lopes et al., 2018; Myer et al., 2005; Podraza & White, 2010). A recent 10-year review of netball showed ankle and knee injuries have increased over the review period and remained a significant problem (Belcher et al., 2020; McManus et al., 2006). In fact, ankle and knee injuries cost the Accident Compensation Corporation (ACC) (a no-fault national insurance system in NZ) NZD$18,049,370 in 2017 alone.

To reduce injuries, Netball New Zealand (NNZ) has partnered with the ACC to create an injury prevention programme (IPP) known as 'NetballSmart'. One of the programmes initiatives was the development of a neuromuscular warm-up, adapted from the FIFA 11+, known as the NetballSmart Dynamic Warm-up (NSDW). Several neuromuscular warm-up programmes have shown some level of success at reducing injury risk in various sports, including the FIFA

11+ (Bizzini & Dvorak, 2015; LaBella et al., 2011; Lopes et al., 2018; Pfile, Gribble, Buskirk, Meserth, & Pietrosimone, 2016). As the FIFA 11+ was initially designed as a warm-up in football, adaptations were required to better reflect the movement demands of netball (Bizzini & Dvorak, 2015; Longo et al., 2012). As a result, the NSDW (https://www.netballsmart.co.nz/images/netball-smart/pdf/NSDWU_Summary.pdf) has increased emphasis on jump-landing technique and deceleration control (Fox et al., 2013; Hopper et al., 2017; Otago, 2004). Some of the key points emphasised for landing training in NSDW are, 'soft knee' landings with a reduction knee abduction moment and stable balanced upper body position.

The NSDW was released nationally in 2016, but like other neuromuscular warm-ups barriers to adherence were found, including the warm-ups length and complexity (Martinez et al., 2017; Saunders et al., 2010). NNZ therefore developed an adapted, shortened five-minute Power Warm-up (PWU) (https://www.netballsmart.co.nz/images/netball-smart/pdf/NetballSmart_Power_Warm-Up.pdf) to address some of these barriers. The PWU retained the jump-landing and deceleration exercises as they were considered essential to game preparation. The strength exercises from the NSDW were removed and some exercises were combined to decrease the warm-up duration. As with similar warm-up programmes, removal of some exercises raises concern that the effectiveness of the NSDW will be lost (Bizzini & Dvorak, 2015; Fulcher et al., 2018). For example, removing exercises (Nordic hamstring curl, core and trunk stabilising exercises), previously shown to reduce injury risk, could decrease the positive effects of the NSDW (Fulcher et al., 2018; LaBella et al., 2011; Thomas et al., 2017a).

An initial evaluation of the NSDW reported it could improve some physical performance outcomes in 13-15-year-old players; however, there was no investigation of landing technique (McKenzie et al., 2019). Thus, further research is needed to investigate the effects of NSDW in the older 15-18-year-old youth group, focused on landing technique. Similarly, with the creation of the shortened PWU a comparison of the effectiveness of the two warm-ups at improving landing technique is prudent. Thus, the purpose of this study was to evaluate whether the full NSDW and PWU can improve landing technique in 15-18-year-old netball players and which is most effective.

Methods

Participants

Initially 92 participants were recruited to undertake this study, however only 77 participants from 12 teams (six different schools) completed both the pre- and post-testing and were included in the analysis. Each of the six school's 1st and 3rd ranked teams participated in the study, allowing for some stratification of experience and skill level across the schools. A cluster randomised controlled design was applied, where schools were identified from a public list of those that competed in a recent secondary school tournament. Random allocation via computer placed the school (two teams) into either NSDW group (*n* = 37, age 15.9yr ± 0.89; height 172.6cm ± 7.28; weight 70kg ± 10.46) or PWU (*n* = 40, age 15.7yr ± 0.89; height 170.4cm ± 7.11; weight 68kg ± 10.63). Therefore, all players from each team within a school were assigned the same warm-up, avoiding treatment contamination bias, reducing the chance of either group inadvertently carrying out the others warm-up protocol. All participants were healthy and free from injury in the previous six months and were training and competing in a secondary school netball programme at the time of data collection. All teams were involved in two netball-specific training sessions and one competitive game per week (duration the same for all participants). Prior to involvement, all participants and guardians were fully informed of the study procedures before giving their informed consent and assent, the study was approved by Auckland University of Technology Ethics Committee (AUTEC) 19/25.

Intervention

After allocation, participating coaches and players underwent a practical teaching session pre-season on performing the warm-up correctly. Coaches were given extra guidance by a trained physiotherapist on correct landing and exercise technique, as well as how to access online resources to help through the season. Coaches have indicated they are more likely to adhere to IPPs if they have access to resources and are given practical, professionally taught sessions on the exercises (Saunders et al., 2010). The teaching session also covered how to adapt the program to increase motivation amongst the players but retain fidelity of the exercises. Examples included changing exercise sequence, the direction players ran through the warm-up (facing each other) and internal and external focus instructions to improve motor learning (Andrieux, Danna, & Thon, 2012; Gokeler et al., 2018). Additionally, coaches were shown how to safely incorporate a netball and perturbation in the air or on the ground to some of the warm-up exercises, replicating unpredictable game contact (Gokeler et al., 2018; Pfile et al., 2016). They were also encouraged to let the players run the warm-up themselves once they were comfortable with the content of the exercises, offering some control over the program whilst still allowing the coaches to monitor movement quality (Andrieux et al., 2012). Both groups performed their allocated warm-up 3-times weekly prior to each training and game session, for a 12-week period. The NSDW group could remove the strength section of the warm-up on game days. The primary researcher undertook two follow-up meetings at the 4-week and 8-week period of the study to further educate coaches on refining movement technique, encourage adherence and suggest exercise progressions. The coaches took an attendance record for each training and game day session to monitor compliance. The participants were asked to fill in a simple diary showing their weekly activity, including number of strengthening or cardiovascular exercise specific sessions and if they performed the NSDW or PWU with any other netball teams. There can be large variability between individuals somatic and biological maturity of the same chronological age (CA), around the adolescent growth spurt. A modified Mirwald offset ((years) = -7.709133 + (0.0042232 x (age x stature)); was measured to better describe the population and account for any effect of maturation stratification on the results of the study (Kozieł & Malina, 2018).

Testing Procedure

All testing was conducted within 2-3 weeks of season start, within the school gym environment that each team trained throughout their season. Field-testing at the schools was chosen to improve ecological validity and reduce routine interruptions. A series of bilateral and unilateral drop vertical jumps (DVJ) were used to assess landing technique. Outcome measures included the Landing Error Score System (LESS), peak vertical ground reaction force (GRF) and frontal plane projection angle (FPPA). All test protocols have been used in previous research (Bates et al., 2013; Greska, Cortes, Van Lunen, & Oñate, 2012; McKenzie et al., 2019). Each observer/researcher was responsible for measuring a single test using the same standardized protocol, to improve within-session reliability. Testing was repeated within 2-3 weeks post the 12-week study period.

The DVJ (bilateral and unilateral) was performed on a portable force plate (AMTI, Advanced Mechanical Technology Inc, Watertown, MA, USA) sampling at 1000 Hz with two 2D video cameras placed to offer both a frontal and sagittal view. Each participant performed three trials, initially standing erect on top of a 30-cm box. The participant then dropped down on to the force plate, swinging arms down before immediately being asked to perform a maximal jump, swinging arms up as if to catch a high pass and then landing back onto the force plate. They were encouraged to achieve a maximal effort, by placing the force plate next to a netball goal post, replicating 'game visual' motivation. Throughout the emphasis remained on achieving maximal jump height, whilst still maintaining control of the landing.

Peak vertical ground reaction force: Peak vertical GRF was measured upon the landing moment of the DVJ, rather than the drop-down motion. The measurement was taken in this manner as previous research has suggested that the second landing of a DVJ may exhibit greater perturbation and better represent in-game mechanics associated with ACL injury risk (Bates et al., 2013). Likewise, as the study is focusing on landing technique, it seemed pragmatic to take GRF from the controlled landing motion of the test. Each participant performed three successful double-leg landings, then repeated the same three trials landing on each single-leg only. The mean results of the three trials for double and single-leg landings were analysed in a custom-made LabVIEW programme (National Instruments, 2014, Auckland, NZ).

Frontal plane projection angle: Tape or black marker-pen circular dots (9mm) were attached or drawn to the anterior superior iliac spine (ASIS), inferior pole of the patella (to approximate the knee joint centre), and the midpoint between the malleoli (to approximate the ankle joint centre). The placement of all markers was performed by the primary researcher, who had experience and training in human anatomy, surface palpation of anatomical landmarks and placing markers for motion analysis data collections. FPPA was measured by drawing a line from the ASIS marker to the knee joint marker, then down to the ankle joint marker, using Kinovea© (www.kinovea.org, v.0.8.15). A FFPA measurement of 0 degrees represents a neutral position of the knee in the frontal plane, negative values represent a valgus knee angle and positive values a varus knee angle (Greska et al., 2012). The mean FPPA value from 3 successful Right and Left single-leg DVJ was used for analysis.

Landing error scoring system (LESS): Landing error scoring system (LESS) is a clinical movement-analysis tool, which uses a criteria list and subjective scoring system to evaluate overall landing technique (Padua et al., 2015). Body position changes between point of initial contact, the frame immediately before the foot was flat on the ground, and at maximal knee flexion were examined. The LESS primarily uses a dichotomous scoring to identify obvious movement errors, such as limited knee flexion or excessive medial knee displacement. With a maximum point score of 17, even a 1-point differential in the total LESS score can be associated with a moderate difference in biomechanical landing technique (Padua et al., 2015). A higher LESS score indicates a greater number of landing errors and consequently poorer jump-landing technique. The mean LESS score from 3 successful trials was used for data analyses.

Statistical Analysis

Shapiro-Wilk test and visual review of histograms was performed to assess normality. Paired t-tests determined pre-post differences in all landing technique measures for the NSDW and PWU groups. Mean differences and associated 95% confidence intervals and Hedges' g effect sizes (ES) were reported. The following scale was used to interpret the magnitude of the ES: >4 (extremely large), 2.0-3.99 (very large), 1.2-1.99 (large), 0.6-1.19 (moderate), 0.2-0.59 (small) (Hopkins, Marshall, Batterham, & Hanin, 2009). Generalised linear mixed effects models were developed to evaluate the effects between the NSDW and PWU groups. This process accounted for the cluster design using multiple sites (schools) and repeated measures (random effects). Initial models were performed accounting for the variables Mirwald offset, number of strength specific and cardiovascular training sessions, but as these showed no significant effect on the analysis the final model ran without these variables. All models controlled for baseline measures, gamma distribution was used for positive scores and normal distribution for FPPA negative scores. The threshold for statistical significance was set at $p < 0.05$ for all analyses. Both the Statistical Package for the Social Sciences (SPSS) (IBM SPSS Statistics v.26; IBM Corporation, Chicago, IL) and Stata (STATA v.16, College Park, TX) were used to perform the analyses.

Results

Demographics were not significantly different between the NSDW and PWU groups (p > 0.05) (Table 1). All participants showed a high level of compliance to the program (NSDW = 92% ± 1%; PWU = 88% ± 1%) and were included in the analysis. Results from the paired t-tests show both warm-up groups significantly improved landing technique measures (ES Range- **GRF** = -0.6 to -1.1; **FPPA** =0.8 to 1.2; **LESS** = -1.6 to-3.2; p<0.05) (Table 2). Results of mixed effects models revealed that there were no statistically significant differences between groups for GRF and FFPA but revealed that the PWU warm-up group resulted in statistically significant improvements in LESS scores, over the NSDW warm-up group (Table 3). The PWU group had on average a 0.30 (p =0.001) greater reduction in LESS score compared to the NSDW.

Table 1: Comparison of demographics, training sessions and compliance between groups.

	NSDW (*n =37)* **Mean ± SD**	**PWU (*n* =40)** **Mean ± SD**
Age	15.9 ± 0.9	15.7 ± 0.9
Weight (kg)	69.0 ± 10.5	67.1 ± 10.8
Height (cm)	172.6 ± 7.3	170.4 ± 7.1
Mirwald Offset	3.9 ± 0.8	3.6 ± 0.8
Cardiovascular Sessions (n)	6.0 ± 9.8	2.8 ± 4.2
Strength Sessions (n)	7.7 ± 9.5	5.2 ± 9.1
Warm-up Compliance (%)	92 ± 0.08	88.1% ± 0.09

NSDW = NetballSmart Dynamic Warm-up; PWU = Power warm-up; SD = Standard deviation; n = number of sessions over study period

Table 2: Mean Pre-Post differences for both groups.

	Pre-Test Mean ± SD	**Post Test Mean ± SD**	**Difference in Mean (95% CI)**	**Effect Size (95% CI)**	**P Value**
NSDW (*n* =37)					
GRF DL (N)	3234 ± 930	2591 ± 584	-642 (343 to 942)	-0.8 (-0.3 to -1.3)	0.001*
GRF Right SL (N)	2862 ± 746	2482 ± 551	-380 (142 to 617)	-0.6 (-0.1 to -1.0)	0.003*
GRF Left SL(N)	2768 ± 728	2183 ± 737	-585 (-301 to 890)	-0.8 (-0.3 to -1.3)	0.001*
FPPA Right (°)	-13.8 ± 6.7	-7.7 ± 8.3	6.1 (3.3 to 8.8)	0.8 (0.3 to 1.3)	0.001*
FPPA Left (°)	-13.6 ± 5.8	-5.1 ± 8.4	8.5 (6.4 to 8.4)	1.2 (0.7 to 1.7)	0.001*
Landing Error Score	7.9 ± 2.1	4.9 ± 1.6	-3.0 (-2.3 to -3.6)	-1.6 (-1.1 to -2.1)	0.001*
PWU (*n* =40)					
GRF DL (N)	3452 ± 963	2566 ± 610	-886 (-539 to -1233)	-1.1 (-0.6 to -1.6)	0.001*
GRF Right SL (N)	3148 ± 743	2571 ± 527	-576 (-315 to -839)	-0.9 (-0.4 to -1.4)	0.001*
GRF Left SL (N)	3251 ± 713	2516 ± 586	-735 (-492 to -978)	-1.1 (-0.6 to -1.6)	0.001*
FPPA Right (°)	-14.0 ± 7.3	-5.9 ± 6.0	8.1 (5.7 to 10.4)	1.2 (0.7 to 1.7)	0.001*
FPPA Left (°)	-14.9 ± 7.8	-5.7 ± 8.0	9.1 (6.6 to 11.7)	1.2 (0.7 to 1.6)	0.001*
Landing Error Score	9.17 ± 1.91	3.86 ± 1.31	-5.31 (-4.71 to -5.91)	-3.2 (-2.5 to -3.9)	0.001*

NSDW = NetballSmart Dynamic Warm-up; PWU = Power warm-up; CI = confidence interval; * significantly different pre-post (P <0.05). GRF= ground reaction force, FPPA= frontal plane projection angle, DL=double leg, SL=single leg; N= newtons.

Table 3: Outcomes of mixed models comparing the effects between the two warm-ups.

Model	Variable	ß (95%CI)	Robust Std. Error	t	P Value
1	GRF DL (N)	-0.02 (-0.14 to 0.10)	0.06	-0.33	0.743
2	GRF Right SL (N)	0.01 (-0.04 to 0.07)	0.03	0.42	0.677
3	GRF Left SL (N)	0.08 (-0.16 to 0.32)	0.12	0.65	0.516
4	FPPA Right (º)	1.83 (-2.56 to 6.22)	2.24	0.82	0.413
5	FPPA Left (º)	0.20 (-1.82 to -2.22)	1.03	0.19	0.194
6	Landing Error Score	-0.30 (-0.20 to -0.39)	0.05	-6.25	0.001*

GRF= ground reaction force, FPPA= frontal plane projection angle, DL=double leg, SL=single leg; N= newtons;* significantly different (P <0.05). Coefficient estimates the average difference in effect between the 2 groups.

Discussion

Jump-landing is an important, frequently performed movement in netball and poor landing technique is commonly identified as a major contributor to injury in female sports (Hewett et al., 2010; McManus et al., 2006; Stuelcken et al., 2016). There are no previous studies reporting the efficacy of the NSDW or PWU on their ability to improve landing technique measures. This study indicates a significant reduction in peak vertical GRF, improved frontal plane knee position, and overall landing technique following both warm-ups.

One of our study's findings, was the improvement in FPPA which is commonly used as a surrogate measure of valgus knee angle (Table. 2). A significant proportion of the content of both warm-up programmes incorporated repeated plyometric jumps, cutting and deceleration exercises challenging knee stability. The warm-up exercises therefore, likely encouraged positive neuromuscular adaptations and dynamic control of the players knee position (Hewett et al., 2010; McManus et al., 2006; Myer et al., 2005). Likewise, the pre-study teachings advised coaches to encourage internal and external feedback on landing technique, such as 'soft' greater knee flexion and reduced GRF landings and avoidance of in-ward knee collapse. The intention of this was to improve players awareness of biomechanically high-risk positions (Andrieux et al., 2012; Gokeler et al., 2018). Increased knee valgus angle on landing has long been linked in research to risk of injury, notably to the ACL and Patellofemoral joint (PFJ) (Boling et al., 2010; Hewett et al., 2010). A decrease in knee valgus angle has similarly been identified as a positive outcome in several previous research publications, investigating the efficacy of neuromuscular training and or warm-up programs in female players (Hopper et al., 2017; Lopes et al., 2018; Myer et al., 2005). However, recent research has suggested that frontal plane abduction of the knee itself may not actually be the initiating factor in "valgus collapse' (Dai et al., 2012; Quatman et al., 2010). Instead, it may be the last motion in a chain reaction, where first the hip internally rotates and then to balance this motion the tibia externally rotates in relation to the femur. This may result in an elongation of the ACL and impingement against the lateral aspect of the condylar notch, increasing injury risk (Dai et al., 2012; Quatman et al., 2010). Thus, FPPA and valgus angle may only be a small mitigating factor for lower-limb injury and therefore IPP implementors attempting to improve landing technique may need to focus on additional landing mechanics.

There was also significant reduction in LESS score for the NSDW warm-up and PWU. A LESS score of 5 or above is considered an indicator of increased biomechanical risk of ACL injury for a player (Padua et al., 2015). The mean LESS scores for both groups' pre-study were above this cut-off (NSDW = 7.9 and PWU = 9.2) and below this cut-off after study completion (NSDW= 4.9 and PWU = 3.9) (Table. 2). This suggests that both warm-ups were successful at improving landing technique biomechanics. Coaches were directed to encourage flexed knee, hip, and trunk landings, whilst maintaining stable body position. These instructions would inherently increase lower-extremity joint displacement from initial contact to completed jump-land position and improve LESS scores in both warm-up programmes. Decreased lower-extremity (hip, knee, and ankle) joint displacement are identified sagittal plane errors within LESS and often associated with injury risk (Padua et al., 2015). Previous research into a similar neuromuscular training programme in college aged female basketball players also showed an improvement in LESS (score reduced on average by 2.4 points), though the programme only ran for 6-weeks, possibly accounting for the smaller improvement (Pfile et al., 2016). There is however, no evidence that adopting a cut-off score of five on the LESS and applying it to an independent cohort is able to reduce injury risk (Padua et al., 2015; Pfile et al., 2016). Similarly, ACL injuries frequently occur in netball during jump tasks that involve significant horizontal momentum, in combination with rotation and/or after a physical perturbation (player contact) prior to landing (Stuelcken et al., 2016). Additionally, cognitive demands on a player, such as having to react to the unanticipated moves of an opponent, are also theorised to contribute to ACL injury (Gokeler et al., 2018; Stuelcken et al., 2016). These elements are not evaluated in the DVJ task, reducing the validity of LESS to measure netball jump-lading tasks. Therefore, though the LESS is a valid and reliable measure for assessing jump-landing biomechanics, it would be prudent to not overestimate LESS as tool for predicting injury risk during netball specific jump-landing demands (Myer et al., 2005; Padua et al., 2015).

The final assessment of landing technique to show significant improvement in both warm-ups was peak vertical GRF. Whether single-leg landing or bilateral, all GRF outcomes reduced after 12-weeks. One of the simplest ways of lowering peak vertical GRF during landing appears to be greater knee flexion on landing (Bates et al., 2013; Hopper et al., 2017; Podraza & White, 2010). Coaches were encouraged to analyse and improve their players landings during warm-up, stressing the importance of a flexed 'soft' knee technique both on a single and double-leg landing. Though no direct causal relationship has been shown between GRF and injury, it is generally accepted that reducing GRF will likely have some effect on reducing the frequency of lower-extremity injuries (Bates et al., 2013; Boling et al., 2010; Podraza & White, 2010). The footwork rules of netball demand the player stop with the ball in hand, creating large deceleration forces (Otago, 2004). Steele (1988), found mean peak GRF values for netball landings ranging from 3.9 Body weight (BW) to 5.4BW, with a higher force on high pass landings compared to standard passes. A reduction in peak GRF would therefore seem beneficial for decreasing the risk of lower-extremity injury in netball players (Otago, 2004; Steele, 1988).

There were no significant differences between the two warm-ups in terms of changes in GRF or FPPA. Interestingly, the PWU group did improve more on the LESS (Table. 3). This may be because there is diminishing return with plyometric exercises or technique training, where performing one drill is as effective as two or three jumping and running drills? Alternatively, the exercises removed for the PWU (‘core exercises’, Nordics, some running drills), have little relationship to the studies outcome measures, while the exercise retained in both warm-ups (squats, single and double leg jump/landing exercises) were more closely linked to the measures taken.

The strength of this study was that both warm-up programmes were coach led in their own training environment. As coaches remain one of the key stake holders in the successful implementation of an IPP (Fulcher et al., 2018; Martinez et al., 2017; Saunders et al., 2010; Thomas et al., 2017b). Additionally, coaches have indicated that running an IPP effectively requires teaching correct exercise technique, understanding why content has been chosen and an opportunity to access resources and support throughout the program (Fulcher et al., 2018; Saunders et al., 2010). Both warm-up methods in this study included an in-depth teaching session covering all the above coaching needs, with an option for feedback throughout the study on exercise progression or adaptation whilst maintaining fidelity and improving player motivation (Gokeler et al., 2018; Martinez et al., 2017; Saunders et al., 2010). This is likely why compliance to the programmes over the 12-week period was so high. Players weekly diaries and attendance records indicated high (NSDW = 92% PWU = 88%) compliance to the warm-up sessions. Subsequently, once extra warm-up performances at club/centre teams were extracted from the players weekly diaries, it appears all 77 participants managed to perform three warm-up sessions a week (36 sessions over 12-weeks) or more. A strength of both warm-ups used in this study, was their multi-modal exercise content, as they included a variety of (balance, strength, plyometric, single and double jump/landing) movements. It is suggested that neuromuscular IPPs/warm-ups are more likely to be effective at reducing injury risk and improving performance if a combination of the exercise movements above are performed (Hopper et al., 2017; Lopes et al., 2018; Myer et al., 2005). Attention to technique quality and adaptability for motivation from the coaches running the programmes, along with the warm-ups multi-modal exercise content and high compliance was likely a major contributor to the improvements seen (Andrieux et al., 2012; Martinez et al., 2017; Saunders et al., 2010).

A final limitation of this study is that intra-cluster correlation analysis was not performed . This may have led to an underestimation of the *P*-values and risk of incorrectly narrowing the 95% CIs, underestimating the uncertainty of the findings (Emery, 2007). A greater number of school clusters would have been ideal and provided more confidence in the statistical outcomes of the study.

Conclusions

The results of this study show that both the NSDW and PWU neuromuscular warm-ups improved landing biomechanics (GRF, FPPA) and technique (LESS), potentially decreasing knee injury risk in youth female netballers. It is recommended that coaches should consider implementing one of the two warm-ups in their netball programmes. Their choice of warm-up will likely be dependent on the environment they are performing in and time demands.

Practical Implications

- The NetballSmart dynamic warm-up and NetballSmart Power warm-up both significantly improved landing technique over a 12-week training period in youth female netball players.
- The longer (NSDW) warm-up was not superior to the shorter (PWU) and we recommend that coaches should consider implementing either in their netball programmes, choice of which will likely be dependent on the environment.
- We recommend coaches have access to a teaching programme on how to use the warm-up programmes, safely and effectively. Teaching programmes for coaches should focus on analysing and correcting movement technique in the warm-up, whilst developing the ability to adapt the programme to improve motivation yet retain exercise effectiveness.

CHAPTER SIX: IMPROVED PERFORMANCE IN YOUTH NETBALLERS USING TWO DIFFERENT LENGTH NETBALL SPECIFIC WARM-UPS.

Prelude

The study in this chapter was run concurrently with the same participants, using the same allocation methodology as in the previous *Chapter 5*. The pre and post testing outcomes for *Chapter 5* and *6* were also undertaken at the same time. The main body of the study in *Chapter 6* will not pertain to the fact above, as it has been written in the style of a standalone manuscript created for submission to a separate journal to that of *Chapter 5.* The focus of this chapter is to report the effectiveness of two of NIPP's warm-up programmes from a performance perspective. Coaches were identified in *chapter two* as one of the main implementors of IPP's and they are often thought to have a focus on performance above injury prevention. Therefore, if the warm-ups can be shown to improve performance and greater met the needs or values of the coach, there is likely to be greater adoption of the warm-ups within the netball community. Testing the effectiveness of IPP resources is an essential step of a programme endorsement and development.

This chapter comprises the following paper to be submitted to the International Journal of Sports Science & Coaching:

Belcher, S., Whatman, C., Brughelli, M., & Borotkanics, R. (2021). Improved performance in youth netballers using two different length netball specific warm-ups. *International Journal of Sports Science & Coaching.* (In Review).

Abstract

Purpose: Neuromuscular warm-up has been shown to reduce injury risk and improve performance; however, barriers to implementation are common. To improve uptake by coaches Netball New Zealand developed two warm-ups of differing complexity and duration. This cluster randomized control trial investigated the association between two netball specific warm-ups and improvements in performance outcomes in youth netball players.

Methods: Twelve teams from six schools performed either the NetballSmart Dynamic Warm-up (NSDW, n = 37); or Power warm-up (PWU, n = 40), three times a week for 12 weeks. Performance was measured using 505 change-of-direction (COD), isometric mid-thigh pull (IMTP), Y-balance, vertical jump (VJ) and horizontal jump (HJ) tests. Paired t-tests assessed mean differences pre and post the interventions. Generalised linear mixed effects models evaluated effects between the NSDW and PWU groups.

Results: There was no significant difference between the NSDW or PWU for any of the outcomes (all $p > 0.05$). Significant improvements were found in Y-balance (**NSDW**: Right (R) = 6.4cm, Left (L) = 7.5cm, p =0.001; **PWU:** R= 4.2cm, P = 0.004, L= 4.2cm, p = 0.006) and IMTP (**NSDW**: 162.2n; **PWU**: 151.1n, p = 0.001) for both warm-up groups, and the **NSDW** also enhanced 505 performance (-0.07s, p = 0.024). VJ and HJ failed to improve for either warm-up.

Conclusion: Based on performance outcomes coaches should be free to choose the warm-up they feel best fits their team environment, reducing barriers to implementation. Additionally, they may benefit from adding further COD, horizontal and vertical jumping movements to either their warm-up or skills training sessions.

Keywords: Netball, Neuromuscular warm-up, Youth, Performance

Introduction

Netball is a popular sport amongst females in the commonwealth countries (Otago, 2004) and the most popular for females at secondary school (Netball New Zealand, 2019b). Netball requires explosive movements (jump-landing, changing of direction (COD), cutting, accelerating and decelerating the body), performed at near-maximum levels of muscular strength and power production (Fox et al., 2013; Mothersole, Cronin, & Harris, 2013). Jumping is frequently performed in netball to receive, defend, intercept or rebound for the ball. Jump-landing movements are believed to occur 60-120 times a game, with players landing unilaterally 67% of the time[5]. For attacking players 66% of their jumps occur whilst turning in flight, in addition to performing a subsequent jump upon landing 32% of the time (Lavipour, 2011). Another key netball movement is a COD, which occurs approximately every 2.8 seconds during a match (Davidson & Trewartha, 2008; Thomas, Comfort, Jones, & Dos'Santos, 2017a). Additionally, the footwork restriction of being unable to take a step whilst in possession of the ball, demands players must perform feats of rapid deceleration under pressure (Ferreira & Spamer, 2010; Fox et al., 2013; Otago, 2004).

A warm-up is a set of preparatory exercises aimed at increasing preparedness for sporting activity to maximize performance and decrease the risk of injury (Silva, Neiva, Marques, Izquierdo, & Marinho, 2018). For players to tolerate explosive movements on court and perform at their best, a preparatory warm-up for netball must attempt to mimic the game demands. Netball New Zealand (NNZ) in partnership with the Accident Compensation Corporation (ACC) (a no-fault national insurance system) developed the NetballSmart Dynamic warm-up (NSDW), an adaptation of the 11+. The 11+ warm-up was designed to prepare the body for soccer (Bizzini et al., 2013; Longo et al., 2012), but would not necessarily meet the game demands of netball. The adapted NSDW (https://www.netballsmart.co.nz/images/netball-smart/pdf/NSDWU_Summary.pdf) better mimics the fundamental movements of netball jumping whilst turning in the air, changing direction and fast deceleration movements (Otago, 2004; Stuelcken et al., 2016). The NSDW was released nationally in 2016, but like other injury prevention program (IPP) warm-ups, barriers to acceptance and implementation were encountered. Reasons for poor uptake and adoption include lengthy warm-up time, too many sets/reps for young players and boredom (Martinez et al., 2017; O'Brien et al., 2017a; Saunders et al., 2010). Netball NZ therefore created an adapted, shortened eight-ten minute Power Warm-up (PWU) (https://www.netballsmart.co.nz/images/netball-smart/pdf/NetballSmart_Power_Warm-Up.pdf) to reduce some of the proposed barriers. In creating the PWU, the strength section was removed from the NSDW and a few of the other exercise were combined, decreasing warm-up duration. Though the primary aim of the NSDW and PWU was to reduce netball injuries, improved physical performance was also a desired outcome. The belief was that performance enhancement would act as motivation for uptake, adherence and acceptance (Saunders et al., 2010; White et al., 2014). Club managers and coaches remain important stakeholders in the distribution and successful implementation of national warm-up IPPs, but often it is difficult to positively affect uptake based solely on injury prevention (White et al., 2014; Zarei et al., 2018). If a positive effect on players' performance or increased emphasis on player availability due to reduced injury was offered as outcomes of an IPP, acceptance may be higher (Saunders et al., 2010; Steffen et al., 2013; Zarei et al., 2018). It would therefore seem ideal to show an IPP warm-up not only reduces injury incidence but demonstrates players' performance improvements as well.

There is a growing body of research suggesting warm-up programs can have a positive effect on improving selected performance measures in some sports (football, basketball, futsal, netball) (Ayala et al., 2017; Kilding, Tunstall, & Kuzmic, 2008; McKenzie et al., 2019; Reis, Rebelo, Krustrup, & Brito, 2013; Zarei et al., 2018). Early research has evaluated the performance benefits of the original NSDW in 13-15-year-old netball players, reporting an improvement in prone hold, balance and vertical jump performance, important physical components in netball (McKenzie et al., 2019). Similar studies utilising the 11+ warm-up have also shown advancements in 20m sprint performance (Kilding et al., 2008), dynamic postural control and single leg hop symmetry (Ayala et al., 2017). The 11+ also improved vertical jump height, prone hold, unilateral lower-limb strength, COD and balance in female athletes (Pardos-Mainer, Casajús, & Gonzalo-Skok, 2019; Parsons, Carswell, Nwoba, & Stenberg, 2019). However, there remains a paucity of research on the effects of warm-up programs on performance outcome improvements in in netball.

With the reduced number of exercises in the PWU, especially removal of the strengthening component, there is some concern the fidelity of the initial NSDW will no longer exists and it will be less effective (Fulcher et al., 2018; Silva et al., 2018). Thus, it is important to determine whether this new warm-up, as well as the original NSDW, are equally effective at improving performance outcomes. Understanding some of the training effects/performance outcomes (Attenborough et al., 2017; Myer et al., 2005; Saunders et al., 2010), may increase acceptance of warm-up programs within the sport. Therefore, the aim of this study was to explore whether either the NSDW or PWU was associated with greater improvements in performance outcomes in 15-18-year-old netball players over a 12-week period .

Materials and Methods

Method

A randomised controlled design was utilised, with schools being identified from a public list of competitors in an annual secondary school tournament. Each school (two teams) was randomly allocated via computer into either the NSDW group or PWU group (Figure 1). All players from each team within a school were allocated the same warm-up intervention, preventing contamination bias. Stratification of experience and skill level across the schools was controlled by accepting participants from each school's 1st and 3rd ranked teams.

After allocation, participating coaches and players underwent a practical workshop pre-season on performing the warm-up correctly. Coaches were given extra guidance by a trained physiotherapist on correct exercise technique and access to online resources through the season. Coaches have indicated they are more likely to adhere to IPPs if they have access to resources and are given practical, professionally taught sessions on exercise correction (Saunders et al., 2010). The workshop also covered how to adapt the program to increase motivation amongst the players but retain fidelity of the exercises. Examples included changing the direction players ran through the warm-up (facing each other), altering exercise sequence pattern and offering internal and external focus instructions to improve motor learning (Andrieux et al., 2012; Gokeler et al., 2018). Additionally, coaches were shown how to safely incorporate perturbation in the air or on the ground and/or a netball to some of the warm-up exercises, replicating unpredictable game responses (Gokeler et al., 2018; Pfile et al., 2016). Coaches also encouraged the players to lead the warm-up themselves once they were comfortable with the exercises, offering some control over the program whilst still allowing the coaches to monitor movement quality (Andrieux et al., 2012). Both groups performed their allocated warm-up 3-times weekly, for a 12-week period. The NSDW group removed the strength section of the warm-up on game days. Two follow-up meetings by the primary researcher occurred at the 4-week and 8-week period of the study to educate coaches on refining movement technique, encourage adherence and suggest exercise progressions. The coaches took an attendance record for each training and game day session to monitor compliance. The participants were asked to fill in a simple diary showing their weekly activity, including number of strengthening (gym) or cardiovascular (running, cycling) exercise specific sessions outside of school and if they performed the NSDW or PWU with any other netball teams. A Mirwald offset was included to better describe the population and account for any effect of maturation.(Mirwald, Baxter-Jones, Bailey, & Beunen, 2002). Please see appendices II & III for the full NSDW and PWU protocols.

Participants

Initially 92 participants from 12 netball teams (six different schools) were recruited in this study, with a total of 77 included in analysis after completing both pre-and post-testing. The 77 participants were placed in either the NSDW group (*n* = 37, age 15.9 ± Standard deviation (SD) 0.89; height 172.6cm ± SD 7.28; weight 70kg ± SD 10.46) or PWU group (*n* = 40, age 15.7 ± SD 0.89; height 170.4cm ± SD 7.11; weight 68kg ± SD 10.63). All participants were free from injury in the previous six months, healthy and were training and competing in a secondary school netball programme at the time of data collection. All teams performed netball-specific training twice a week and one competitive game (duration the same for all participants). Prior to involvement, all participants and guardians were fully informed of the study procedures before giving their informed consent and assent, the study was approved by Auckland University of Technology Ethics Committee (AUTEC) Ref: 19/25.

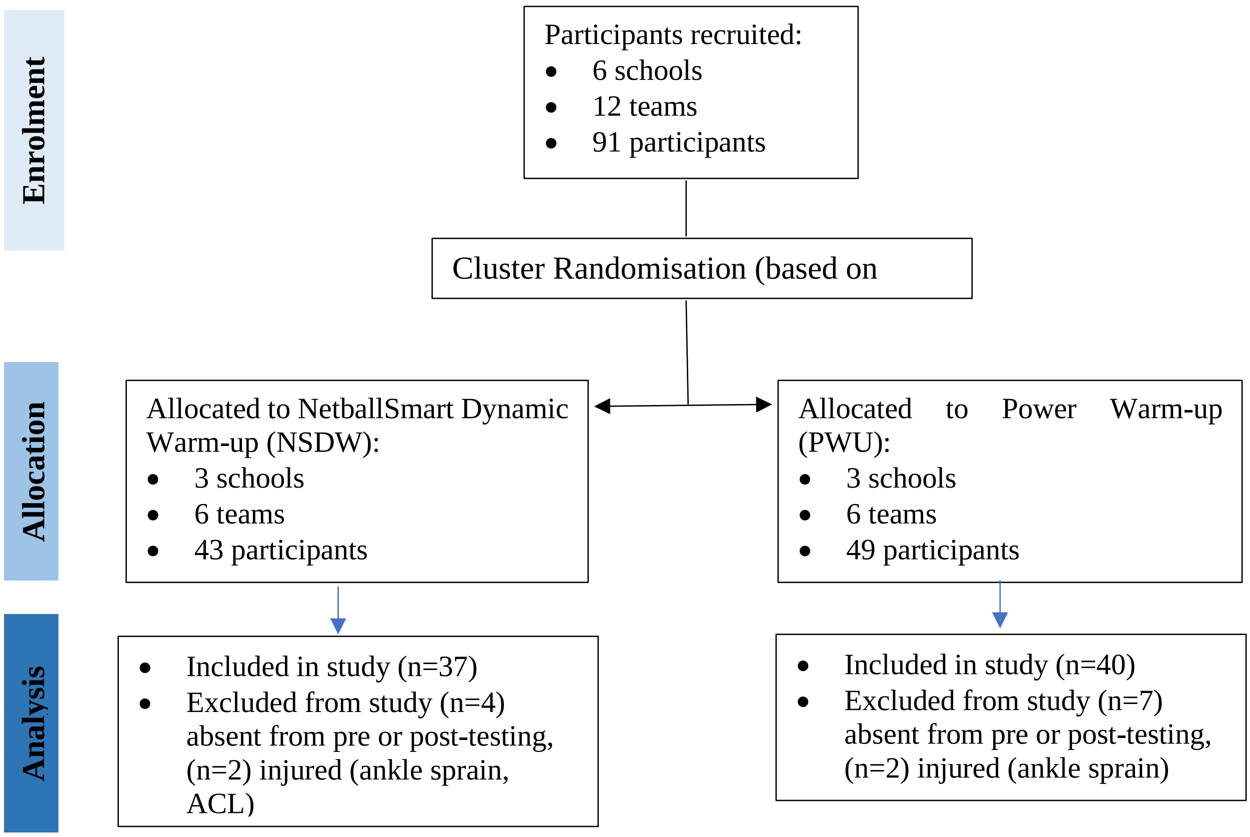


Fig. 1. Flow of participants through study.

Procedures

All testing was conducted within the school gym environment where each team trained throughout their season, 2-3 weeks prior to season start. Field-testing at the schools was elected to improve ecological validity, reducing interruption to team routine. The tests included vertical jump (VJ) height, horizontal jump (HJ) for distance, 505 change of direction, Isometric mid-thigh pull (IMTP) and Y-balance. All test protocols have been used in previous research (McKenzie et al., 2019; Thomas et al., 2017a; Venter, Masterson, Tidbury, & Krkeljas, 2017). Each observer/researcher was responsible for measuring the same test each day using the same standardized protocol, to improve within-session reliability. This process was repeated within 2-3 weeks post the 12-week study period.

Vertical Jump height (VJ). This measure was extracted via a portable force plate (AMTI, Advanced Mechanical Technology Inc, Watertown, MA, USA) sampling at 1000 Hz. Participants initially stood erect on top of a 30-cm box before dropping down on to the force plate, then completing a countermovement jump and reaching up as if to catch a high netball pass and landing back onto the force plate. They were encouraged to achieve a maximal effort, by placing the force plate next to a netball goal post, replicating 'game visual' motivation. Instructions were to achieve maximal jump height, whilst still maintaining control of the landing. Each participant was given several familiarisation trials before the mean score of three successful trials was recorded for analysis. A 30-second break between trials was allowed for recovery. A custom-made LabVIEW programme (National Instruments, 2014, Auckland, NZ) determined jump height through total flight time, using the following equation: jump height = $1/2\ g(t/2)^2$, where $g = 9.81\ \text{m} \cdot \text{sec}^{-2}$ and t = time in air (McKenzie et al., 2019). Vertical jump height measured via a portable force plate has been shown to have good within-session reliability (ICC=0.96; CV=3.6%) (Lake et al., 2018).

505 change of direction. The agility test 505 has been used to test these capabilities in previous studies (Thomas et al., 2017), showing high within-session reliability (ICC = 0.90-0.97), as well as between sessions reliability (ICC = 0.95-0.97) (Barber, Thomas, Jones, McMahon, & Comfort, 2016). Participants ran from a starting line past a 5m-mark, where electronic timing-lights were located, and time started. When participants reached the 10m-line they were required to touch the line and turn 180 degrees and sprint back through the original timing-lights set at the 5m-mark, where time was stopped and recorded to the nearest 0.01 second. After one initial trial to familiarise the participants with the protocol, a further three successful trials were recorded and the mean time used for analysis. There was a 30-second rest period between trials (Barber, Thomas, Jones, McMahon, & Comfort, 2016; Fox et al., 2013; Venter et al., 2017).

Y-balance test (modified star excursion balance test) was used to measure single leg balance (Filipa, Byrnes, Paterno, Myer, & Hewett, 2010; Impellizzeri et al., 2013). All participants were given a minimum of two practice trials to become accustomed to instructions and what constituted exclusion (heel lifted during movement, reaching foot rested down or subject losing balance) (Pfile et al., 2016), before the final three successful trials were recorded. The participants' right and left limb length (LL) was measured from the most distal aspect of the anterior superior iliac spine to the centre of the medial malleolus (Filipa et al., 2010). Y-balance scores were calculated by dividing the maximum reach distance in the anterior (A), posterolateral (PL) and posteromedial (PM) directions by three times the LL of the individual subject, then multiplying by 100; ([A+PL+PM]/[LL x 3] x100) (Filipa et al., 2010). Previous research has reported good inter-rater reliability (ICC =0.88, range = 0.73-1.00) and intra-rater reliability (ICC = 0.88, range = 0.64-0.94) for the Y-balance test (Powden, Dodds & Gabriel, 2019).

Modified horizontal Jump. Participants started with their feet behind a line before being asked to run a 5m distance, then jump from a second line marked perpendicular to a measuring tape (0 cm mark). They jumped as far forward as possible landing on both feet. The participants were required to stick their landing, so jump distance could be measured from the 0 cm mark to the heel of the back foot (Maulder & Cronin, 2005). Participants could step one foot forward for balance, if the heel of the back foot did not lift from the floor. The 5m run up modification as well as the allowance of a step for balance, was included to better replicate movements of netball. If participants did not stick the two-foot landing it was considered a “non-jump” and they were required to repeat the jump until they completed three successful jumps. The mean distance of the three successful trials was used for analysis. A similar testing protocol for standing broad jump (SBJ) or horizontal jump testing, without the initial 5m run-up was shown to have good intra-rater reliability (ICC =0.98) and inter-rater score (ICC = 0.96) (Bates. McPherson, Berry & Hewett, 2017).

Isometric mid-thigh pull (IMTP). Several studies have tested whole-body strength with the use of Isometric Mid-thigh pull (Brady, Harrison, & Comyns, 2020; Dos'Santos et al., 2017; Thomas et al., 2017a). Good reliability of Peak Force (PF) within (ICC = 0.98; CV = 4.5%) and between sessions (ICC= 0.96; CV = 4.6%) has been reported (add Dos’Santos ref here). The IMTP was performed using a portable strain gauge (MT501 Universal Load Cell) at a sample rate of 1000 HZ. Participants were asked to stand in a slight squat position with a 120-130° knee bend and grip onto a bar, hands placed a thumb’s width away from the hips. The participants were then instructed to pull straight up on the bar as hard and fast as they could for three seconds for three repetitions, as if trying to stand from the squat position (Thomas et al., 2017a). Custom software designed using MATLAB 2017a was used for record peak force scores from the successful repetitions and the mean of these three scores used for analysis.

Statistical analysis

Shapiro-Wilk test and visual review of histograms was performed to assess normality. Paired t-tests determined pre-post differences in all landing technique measures for the NSDW and PWU groups. Mean differences and associated 95% confidence intervals and Hedges’ g effect sizes (ES) were reported. The following scale was used to interpret the magnitude of the ES: >4 (extremely large), 2.0-3.99 (very large), 1.2-2.99 (large), 0.6-1.19 (moderate), 0.2-0.59 (small) (Hopkins et al., 2009). Generalised linear mixed effects models were developed to evaluate the effects between the NSDW and PWU groups. This process accounted for the cluster design using multiple sites (schools) and repeated measures (random effects). Initial models included the Mirwald offset and number of strength specific and cardiovascular training sessions, but as these showed no significant effect the final models did not include these variables. All models controlled for baseline values for each respective outcome. The gamma distribution was applied for outcomes whose values could only be positive; the normal distribution was applied for negative scores. School was applied as a random effect. The threshold for statistical significance was set at $p < 0.05$ for all analyses. Both the Statistical Package for the Social Sciences (SPSS) (IBM SPSS Statistics v.26; IBM Corporation, Chicago, IL) and Stata (STATA v.16, College Park, TX) were used to perform the analyses.

Results

Demographics were not significantly different between the NSDW and PWU groups (see Table 1). All participants showed a high level of compliance to the program (NSDW = 92% ± 1%; PWU = 88% ± 1%) and were included in the analysis. The results of the mixed effects models revealed no significant difference between either warm-up intervention, for any of the performance outcomes measured (see Table 2). The NSDW group showed significant improvement in the 505 test (ES = 0.41, p = 0.024), mid-thigh pull strength (ES = 0.98, p = 0.001), Y-balance (R) (ES = 0.46, p = 0.001) and (L) (ES = 0.54, p= 0.001) (Table 2). The PWU group significantly improved in mid-thigh pull strength (ES = 0.85, p = 0.001) and Y-balance (R) (ES = 0.34, p = 0.004) and (L) (ES = 0.34, p= 0.006), but failed to achieve any significant change in the 505 test (see Table 3). Neither warm-up programme resulted in any significant improvement in either vertical jump or horizontal jump performance. Of note, neither warm-up group showed any significant reduction in any performance outcome (see Table 3).

Table 1: Comparison of demographics, training sessions and compliance between groups

	NSDW (*n =37*) **Mean ± SD**	**PWU (*n* =40)** **Mean ± SD**
Age	15.9 ± 0.9	15.7 ± 0.9
Weight (kg)	69.0 ± 10.5	67.1 ± 10.8
Height (cm)	172.6 ± 7.3	170.4 ± 7.1
Mirwald Offset	3.9 ± 0.8	3.6 ± 0.8
Cardiovascular Sessions (n)	6.0 ± 9.8	2.8 ± 4.2
Strength Sessions (n)	7.7 ± 9.5	5.2 ± 9.1
Warm-up Compliance (%)	92 ± 0.08	88 ± 0.09

NSDW = NetballSmart Dynamic Warm-up; PWU = Power warm-up; SD = Standard deviation; n = number of sessions over study period

Table 2: Outcomes of mixed models comparing the effects between the two warm-ups.

Model	Variable	ß (95%CI)	Robust Std. Error	t	P Value
1	505 Agility (s)	0.02 (-0.01 to 0.05)	0.02	1.26	0.210
2	Mid-thigh Pull (N)	-0.01 (-0.08 to 0.06)	0.03	-0.33	0.745
3	Y-Balance Test R (cm)	-0.03 (-0.09 to 0.03)	0.03	-0.96	0.336
4	Y-Balance Test L (cm)	-0.04 (-0.12 to 0.05)	0.04	-0.88	0.381
5	Vertical Jump (cm)	-0.001 (-0.03 to 0.03)	0.02	-0.07	0.946
6	Horizontal Jump (cm)	-0.002 (-0.06 to -0.05)	0.03	-0.06	0.955

N= Newtons, R = Right, L = Left, CI = confidence interval; n= newtons; * significantly different pre-post (P <0.05). ß = Coefficient estimates the average difference in effect between the 2 groups.

Table 3: Mean pre-post differences for both groups.

	Pre-Test Mean ± SD	**Post Test Mean ± SD**	**Difference in Mean (95% CI)**	**Effect Size (95% CI)**	**P Value**
NSDW (*n* =37)					
505 (s)	2.84 ± 0.22	2.77 ± 0.13	-0.07 (-0.13 to -0.01)	-0.41 (-0.87 to 0.05)	0.024*
Mid-thigh Pull (N)	777 ± 141	939 ± 183	162 (102 to 223)	0.98 (0.50 to 1.47)	0.001*
Y-Balance Test R (cm)	98.17 ± 10.91	104.58 ± 16.31	6.42 (2.65 to 10.18)	0.46 (0.01 to 0.92)	0.001*
Y-Balance Test L (cm)	97.53 ± 10.32	105.00 ± 16.87	7.48 (3.52 to 11.43)	0.53 (0.07 to 0.99)	0.001*
Vertical Jump (cm)	24.21 ± 5.16	23.77 ± 4.63	-0.45 (-1.36 to 0.47)	-0.09 (-0.56 to 0.37)	0.329
Horizontal Jump (cm)	216.88± 35.05	219.71± 33.65	2.83 (-4.42 to 10.09)	0.08 (-0.37 to 0.54)	0.434
PWU (*n* =40)					
505 (s)	2.90 ± 0.25	2.85 ± 0.19	-0.05 (-0.11 to 0.01)	-0.23 (-0.67 to 0.21)	0.077
Mid-thigh Pull (N)	789 ± 175	939 ± 177	151 (103 to 199)	0.85 (0.39 to 1.31)	0.001*
Y-Balance Test R (cm)	88.26 ± 11.76	92.38 ± 12.39	4.16 (1.43 to 6.81)	0.34 (-0.10 to 0.78)	0.004*
Y-Balance Test L (cm)	89.06 ± 11.90	93.25 ± 12.38	4.19 (1.27 to 7.11)	0.34 (-0.10 to 0.78)	0.006*
Vertical Jump (cm)	24.88 ± 5.03	24.10 ± 5.21	-0.78 (-2.20 to 0.64)	-0.15 (-0.59 to 0.29)	0.274
Horizontal Jump (cm)	216.06± 36.70	217.82± 24.08	1.76 (-8.18 to 11.69)	0.06 (-0.38 to 0.49)	0.722

NSDW = NetballSmart Dynamic Warm-up; PWU = Power warm-up; Values are mean ± SD = standard deviation; ES = effect size; CI = confidence interval; N= newtons; * significantly different pre-post (P <0.05). R = Right, L = Left, N = Newtons.

Discussion

This study revealed that there was no significant difference in performance outcome between the two netball specific warm-ups. The individual warm-ups in association with the teams regular training and game play both significantly improved strength and balance measures, with the NSDW group also enhancing COD. Coaches could therefore introduce either warm-up protocol and expect some relevant player performance improvements. A previous study reported similar improvements in Y-balance, as well as prone hold and VJ in youth players' using the NSDW (McKenzie et al., 2019). These positive performance results are likewise comparable to other studies investigating various neuromuscular warm-ups (Ayala et al., 2017; Kilding et al., 2008; Parsons et al., 2019). The present study adds to the growing literature showing neuromuscular warm-ups can be effective alongside training at improving some performance measures in youth and that a shorter warm-up can produce similar results.

The warm-up programmes in this study were coach led in their own training environment, giving ecological validity to the research. It is unrealistic to expect a school or club at community level to rely on physiotherapists or strength and conditioning coaches to supervise warm-up routines. Coaches remain an identified key stakeholder in the successful implementation of an IPP (Fulcher et al., 2018; Longo et al., 2012; Saunders et al., 2010). Many coaches have indicated they require education on correct exercise technique, understanding of the rationale behind chosen content and an opportunity to access resources and support throughout the program (Fulcher et al., 2018; Saunders et al., 2010). In this study the warm-up interventions were formally introduced with a detailed teaching session covering all the above coaching needs, with an option for feedback throughout the study on exercise progression or adaptation to improve player motivation, whilst maintaining fidelity (Gokeler et al., 2018; Martinez et al., 2017; Saunders et al., 2010). This likely explains why compliance to the programmes over the 12-week period was so high. Player's weekly diaries and attendance records indicated >80% compliance to their warm-up sessions with their study coach. Subsequently, once extra warm-up performances at club/centre teams were extracted from the players weekly diaries, it appears all 77 participants managed to perform three warm-up sessions a week (36 sessions over 12-weeks) or more. Attention to technique quality, adaptability for motivation from the coaches running the programmes, high compliance and exercise content likely influenced the improvement seen in some of the outcome measures (Andrieux et al., 2012; Martinez et al., 2017; Saunders et al., 2010).

Balance is critical to performing and controlling the explosive actions (jump-landing, change of direction and deceleration) seen frequently in netball.[12,39] This is particularly the case when considering the relatively unique footwork netball rule, that once the player has landed with the ball in hand, the first foot grounded must either stay grounded or be held in the air until the ball is released (Netball New Zealand, 2020). This requires players' to rapidly decrease their horizontal velocity, whilst maintaining balance and stability to stop effectively and not violate the rule (Ferreira & Spamer, 2010; Stuelcken et al. 2016). The Y-balance test is one approach available to appraising player balance.

A key improvement identified in this study was improvement in Y-balance in both groups with no significant difference between groups. The star excursion balance test (SEBT) and simplified Y-balance are commonly used to measure single-leg balance control in comparable studies (Attenborough et al., 2017; Ayala et al., 2017; McKenzie et al., 2019). The improvements in this study are also possibly due in-part to the heavy focus on single-leg jump-landing exercises in both warm-ups. Both warm-ups also include single-leg squats and the NSDW includes single-leg balance strengthening as part of the programme. Moreover, during the pre-study workshops coaches were directed to challenge their players strength in single-leg positions, whilst monitoring and correcting any movement technique faults. This attention to controlling whole body balance during single-leg movements throughout the warm-up programmes, likely facilitated the improvements in Y-balance performance in both warm-up programmes.

Comparisons of these findings to existing studies are important. An 11-week study of youth female football players utilising a similar neuromuscular warm-up to the NSDW, failed to report an improvement in Y-balance (Lindblom et al., 2018). The failure was attributed to poor attendance and therefore poor compliance to training sessions and not enough exercise specific stimulus. In contrast recent studies employing the 11+ in young females (Pardos-Mainer et al., 2019) or the NSDW did show a significant improvement in mean Y-balance score (2.36cm, p = 0.003) (McKenzie et al., 2019). McKenzie et al. (2019), however suggested that balance is such an integral physical component of netball performance, that training and game play alone may be enough to stimulate an improvement in Y-balance over a season. It is likely a combination of the neuromuscular training effect of normal netball play and high compliance to the warm-up programmes, along with strength training resulted in significant Y-balance improvements in both warm-up programs.

In netball, an increase in relative strength is advantageous to producing the high levels of force and absorption that is needed when performing common jump/landing, sprinting and COD game movements (Bailey et al., 2017; Fox et al., 2014; Thomas et al., 2017a, 2017b). Likewise, many movements on the netball court are frequently performed in unstable positions and improved strength can play an important factor in protecting the body and improving movement technique (Lloyd & Oliver, 2012; Myer et al., 2005). A validated measure of this is with the use of Isometric Mid-thigh pull (IMTP) (Thomas et al., 2017a).

Within group strength performance measured through IMTP also improved in this study, for both the NSDW (ES = 0.98, p = 0.001) and PWU group (ES = 0.85, p = 0.001). Again, there was no significant difference in effect found between groups. There was concern the removal of the strengthening specific exercise section from the PWU may limit any potential strength gains. One reason positive results were seen in both warm-up programmes, may be due to the remaining exercises. Both warm-ups still included squat and lunge exercises as part of the routine, as well as plyometric vertical and horizontal jumping movements. These movements likely provided enough stimulus to facilitate strength gains in youth players (Fox et al., 2013; Hopper et al., 2017). Similarly, the IMTP test replicates a resisted squat motion and is similar to that seen in the preparatory initiation of a vertical jump movement (Thomas et al., 2017a). As both programmes still contained squat and jump exercises, an increase in IMTP strength could be expected. Alternatively, any effect due to the removal of the strength section that contained largely core, eccentric hamstring and balance exercises may not have been picked up by the IMTP test.

There is a paucity of studies reporting strength performance changes in youth players after the application of a warm-up intervention, particularly in females. Hopper et al. (2017) were able to show improvement in squat, single-leg squat and lunge as a measure of strength after a short neuromuscular training program in youth netball players. Similarly, a 4-week program on fundamental movements such as squat, lunge and jump showed some improvement in strength in youth age players (Wright, Portas, Evans, & Weston, 2015). Further research into the efficacy of sport specific warm-up protocols on strength performance measures in youth would be beneficial considering the importance of strength on successful sporting outcome and prevention against injury (Myer et al., 2005; Thomas et al., 2017b).

Netball players perform high-intensity change of direction (COD) approximately every six seconds during a 60-minute game, requiring a significant level of control to protect against injury risk, whilst achieving maximum game performance outcomes (Bailey et al., 2017; Davidson & Trewartha, 2008; Fox et al., 2014). COD is consequently an essential performance skill for a netball player, especially considering the movement and area restriction rules enforced on players. In this study 505 performance, indicated any improvements in COD. The final within group performance outcome showing significant improvement was COD, but only in the NSDW group (ES= 0.41, p = 0.02). The reason the longer NSDW may have assisted in COD improvements, is that the programme content includes a specific section on running exercises that closely replicate the 505 test. The PWU includes less running and does not have a featured COD exercise as compared to the NSDW (Plant and Cut). Therefore, the COD training stimulus in the PWU was somewhat less than that of the NSDW. Previous studies have shown that comparable warm-up protocols such as FIFA 11+ improved COD in adult soccer players (Bizzini et al., 2013), youth male futsal (Reis et al., 2013) and child female soccer players (Parsons et al., 2019). Contrastingly, similar studies found trivial or non-significant change (ES: 0.8 to 0.32) in COD after performing warm-up interventions (Kilding et al., 2008; Pardos-Mainer et al., 2019; Steffen et al., 2008), including a recent study on the efficacy of the NSDW (McKenzie et al., 2019). COD is an essential movement of the netball game, therefore an ability to improve this performance skill would make for a compelling argument to coaches wishing to implement the warm-up. The extra running exercises in the NSDW may have helped significantly improve COD, if only with small effect (ES = 0.41, p = 0.02). Therefore, it may be argued that the PWU would benefit returning the plant and cut exercise or adding further COD movements to the warm-up content.

There was no significant change in either VJ or HJ performance measures, which is in keeping with several equivalent studies (Impellizzeri et al., 2013; Lindblom et al., 2018; Steffen et al., 2008). Potentially there are several reasons these performance movements failed to improve, one of which may be the jump/landing technique instructions coaches gave to players throughout the study. Pre-study education to the coaches emphasised achieving maximal jump height or distance was only truly beneficial to performance, if the landing could be controlled. Perhaps coaching instruction therefore did not offer enough stimulus or emphasis on improving jumping explosive movements, over the importance of safe landing. Similarly, testing instructions for both VJ and HJ trials in this study required maximal effort but only within the participants landing capabilities. Previous studies that have indicated improvements in VJ or HJ failed to add safe landing as a testing instruction or specify landing ability as a performance outcome (Bizzini et al., 2013; McKenzie et al., 2019; Zarei et al., 2018), likely influencing a positive result. Requesting controlled landing during testing likely reduced the overall jump height/distance but remains an important recommendation for game ecological validity. Poor landings reduce performance and are a significant injury risk in netball (Otago, 2004; Stuelcken et al., 2016).

Another explanation for the lack of improvement in HJ could be the content of the warm-ups. Neither warm-up contains exercises that notably challenge horizontal jump motion. As both HJ and VJ movements occur regularly within the netball game (catching passes, shooting, intercepts and rebounds), a greater focus on these aspects of performance may help sell the programmes to key stakeholders (O'Brien et al., 2017a; Saunders et al., 2010; White et al., 2014). It would therefore seem prudent to add more VJ and HJ exercises to both warm-up programmes and/or encourage coaches to teach jump-landing technique that improves performance but with an emphasis on safe control of the movements.

A limitation of this study is the effect differing coaching styles may have had on players. Though statistical tests did account for the cluster effect of the schools, there is likely some effect experienced by the players being taught by other netball coaches throughout the study period. Additionally, there was no true control group in this study. This reduces our ability to isolate the effect of the warm-ups on performance outcomes, from the potential effect of normal training throughout the season. Likewise, a greater understanding of the training load for individual players and/or teams would have further enriched the data for this study but may have ultimately placed unrealistic demands upon the school coach’s time. A final limitation of this trial is that intra-cluster correlation analysis was not performed. A result of which may have led to an underestimation of the *P*-values and risk of incorrectly narrowing the 95% CI, reducing the precision of the findings (Emery, 2007). The results of this study would be better generalisable to the netball community, by repeating the research with a greater number of players, differing ages groups, sub/elite and recreational players.

Practical Implications

Either warm-up program can be introduced and sustained by coaches as was evidenced in this study. This study additionally provides evidence that both warm-up interventions were similarly associated with effective improvements in relevant measures of strength and balance performance. These movements are important physical components of netball and possibly could enhance game performance. Evidence of performance enhancement may increase the likelihood of coaches implementing and sustaining these warm-up programmes. This should especially be the case for the shorter PWU, that was adapted to reduce some of the cited barriers stakeholders had noted with the original NSDW. No improvement was seen in HJ or VJ outcomes and the consideration of adding extra jump/landing technique exercises to warm-up programmes may be beneficial to coaches/players. Teams may also benefit from considering a strength and conditioning or exercise programme to be added to their training regime outside of the warm-up, greater increasing their chance of improving explosive jump and COD motions. Both warm-ups performed similarly on evaluated measures, enabling secondary school coaches the ability to choose the warm-up that best fits their team's needs.

CHAPTER SEVEN: LESSONS IN PRACTICAL IMPLEMENTATION: NETBALLSMART A NATIONAL INJURY PREVENTION PROGRAMME.

Prelude

This chapter is a commentary on how the research throughout this thesis has been practically integrated in an existing national injury prevention programme "NetballSmart". It highlights how all the practical implications from the previous chapters have been utilised in a real-world sports setting. It also discusses how research questions aligned with the specific needs of an injury prevention programme (IPP) can lead to greater achievement in the programmes key outcome markers (injury count, cost to insurers and adoption).

This chapter comprises the following paper submitted for publication in the New Zealand Journal of Sports Medicine:

Belcher, S., Whatman, C., & Brughelli, M. Lessons in practical implementation: NetballSmart a national injury prevention programme. *New Zealand Journal of Sports Medicine* (In Submission).

Abstract

There is a clear need for prevention of lower-limb injuries in netball, particularly to the anteriror cruciate ligament (ACL). However, mainy previous injury prevenntion programmes (IPPs) have failed to be implemented, adopted and maintained effectively by their sporting community. One of the identified reasons for IPP failure is a 'resach-to-practice' gap, where the results of injury prevntion studies have failed to be replicable or effective in the real-world sports setting. With this in mind the Accident Compensation Corporation (ACC) (a no-fault national insurance system) partnered with Netball New Zealand (NNZ) in a three-year funded project to create the 'NetballSmart' injury prevention programme (NIPP). This article explores how targeted research can be effectively utilised in the succesful implementation and adoption of a national IPP. Several studies were undertaken to explore which areas of the body were most at risk of injury in netball, possible mechanisms of injury and the effectiveness of two NIPP warm-up resources. The evidence-based resources and educational workshops created from the findings of research, performed under direction of the NIPP in its initial three-years, have contributed to the progarmmes success and a further three-years of investment from the main financier.

Introduction

Netball is a popular sport worldwide, which requires a range of explosive anaerobic movements including repeated sprints, changes of direction (COD), throwing, catching, cutting, jumping and landing (McManus et al., 2006; Fox et al., 2013; Thomas et al., 2017b). Moreover, to avoid violating the unique rule of no-stepping whilst in possession of the ball, players must rapidly decelerate during these tasks (Fox et al., 2013; McManus et al., 2006; Otago, 2004). Netball has a high incidence of injury, particularly to the ankle and knee (Belcher et al, 2020; Downs et al 2020; McManus et al., 2006). Injury to the anterior cruciate ligament (ACL) is the costliest injury in netball (loss of game time and financial cost to insurers) (Fulcher et al., 2018; King et al., 2019; Lohmander et al., 2007). With an 80 to 90%increase in ankle and knee injuries amongst 10-19-year-old netball players between 2008-2017 (Belcher et al., 2020), the Accident Compensation Corporation (ACC) (a no-fault national insurance system) prioritised investment in injury prevention. The ACC partnered with Netball New Zealand (NNZ) in a three-year funded project to create the 'NetballSmart' injury prevention programme (NIPP).

Sports injuries are not only a concern to insurers but the sports organisations themselves, who face the possibility of reductions in participation or avoidance of the game as it is seen as a high injury risk sport. Striving to improve the management and prevention of injuries to make their sport safer is therefore the responsibility of the whole community, as well as those creating legislation (NZ health and safety) or policies (national sports governing bodies) (Finch 2006a; Finch & Cassell, 2006; van Mechelen et al 1992). A collaborative approach between ACC, NNZ and respected members of the netball community identified key areas of focus for the programme. Two of the identified programme priority areas were 'Smart movement' and 'Smart Warm-up". The NIPP 'Smart movement' resources and educational programmes focused on improving technique in fundamental netball movements associated with performance and injury risk (jump-landing, COD, stopping/decelerating) (Hewett et al., 2010; Song et al., 2021; Steulcken et al., 2016). The 'Smart Warm-up' project integrated the various warm-up resources across the NNZ coaching education framework and utilised NetballSmart Development Officers (NDOs) to teach coaches how to effectively use the warm-up as an injury prevention programme (IPP).

There is an increasing body of literature showing that the risk of sustaining a sports-related injury can be substantially reduced through neuromuscular training (NMT) and neuromuscular warm-ups (Emery et al., 2015; Mehl et al., 2018; Sugimoto et al., 2014). Despite the evidence for the efficacy of NMT programmes, many have failed to become widely adopted by sports stakeholders (Players, coaches organisational administrators), for a variety of reasons. (Ageberg et al; Belcher et al 2021b; Bizzini & Dvorak, 2015). Instead, many recreational and professional teams have chosen to utilise their own adapted injury prevention strategies that have not been validated and subsequently may lack effectiveness (Bahr, Thorborg, & Ekstrand, 2015; Fulcher et al., 2018; Myklebust et al., 2013). An IPP will fail to reach full potential unless it is widely implemented amongst its sporting community. The initial focus therefore of any IPP, should be on devising a maintainable implementation plan. The aim of this commentary is to demonstrate how the NIPP reviewed implementation research to devise a practical implementation plan for the first three funded years of the programme. Then it turned the implications from the NIPP targeted research into practical guidance for resource content development and coach education. Finally discussing early signs of successful outcomes for the programme in relation to the implementation process, and what effect this may have on future authentication and recognition for the NIPP.

Building on solid foundations: Developing a practical guide to implementation.

For an IPP to be successful it must first be adopted and endorsed by all stakeholders, whether they be implementors or users. This requires a real-world implementation process, that can maximise the programmes dissemination and adoption (Donaldson et al., 2016; Finch, 2006a). The first step in the review of the NIPP was to review the literature on the barriers and facilitating factors affecting successful implementation of a national IPP (Belcher et al, 2021). This review proposed six-steps to guide successful implementation (Belcher et al., 2021) (**Fig. 1**).

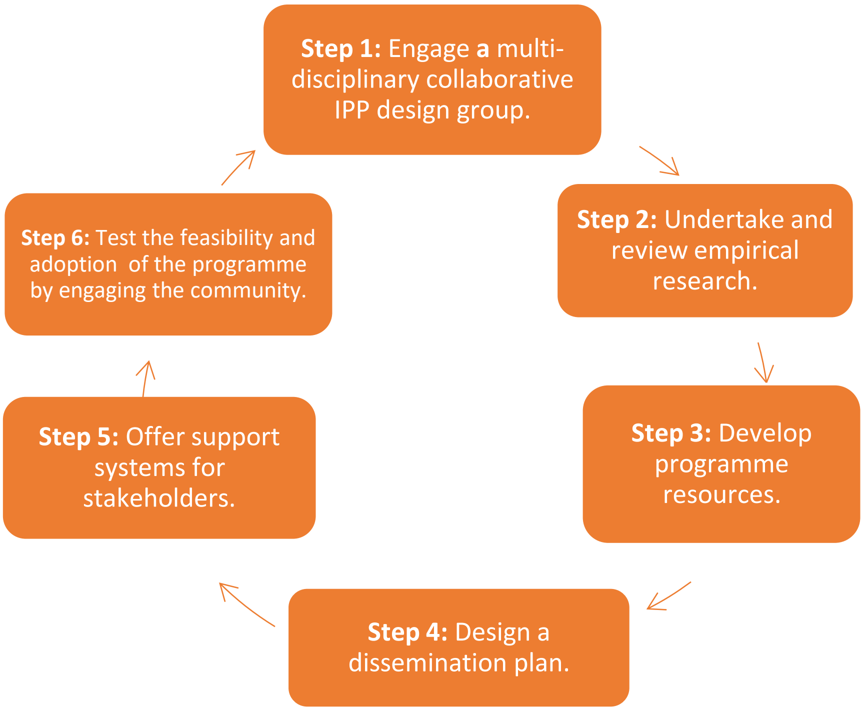


Figure 1. Real-world guide for IPP implementation.

The cyclic nature of the plan offers an opportunity to review the feedback and outcomes within the community, which can then direct the development of the next years educational workshop programmes and resources. The NIPP followed this cyclic process annually.

Year 1: Developing educational workshops and branding.

The first step was to gather a foundation collaborative development group, that would offer the greatest reach within the netball community. This group included members of the ACC (financier), the national sports organisation (NSO) NNZ, regional sports organisations (RSOs) (5 national netball zones and their centres) and respected coaches/players from schools and clubs. This is an important process in implementation, as you need organisational level support to start the programme in the community or build policies that encourage IPP adoption (Donaldson et al., 2016; Richmond et al., 2020). Having the programme endorsed by NNZ was an important step for securing a strong brand for the programme, endorsing educational messaging and increasing dissemination. NNZ started by integrating NIPP messaging in educational coach training booklets for all their junior player (https://www.futureferns.co.nz/) programmes (Years 1-8). Similarly, they placed several NIPP workshops in their accredited coach development framework adding credence to the programme's information (Brown et al., 2016; Frank et al., 2015; McGlashin et al., 2018). The NIPP also employed six NetballSmart development officers geographically spread across the country to conduct educational workshops on injury prevention in local netball centres, clubs and schools. Providing geographically accessible educational workshops within the implementors normal training environment has been recommended to improve uptake (Lindblom., 2018; McGlashin., 2018). Finally, a group of community and nationally respected coaches, players and umpires were asked to come on board as programme ambassadors, to further advocate the messaging (Donaldson et al., 2017; Lindblom., 2018; Saunders et al., 2010). This collaborative group formed a continually active focus group used to review the programmes successes, failures and discuss developmental needs.

Epidemiological research can guide the focus of an IPP by identifying which areas of the body are most at risk, target the content of a programme based on the audience and distinguish any seasonal injury patterns that exist (Brooks et al., 2006; van Mechelen et al., 1992). The collaborative team decided the best way to guide the NIPP was to explore NZ based netball injury data. Therefore, the ACC injury data was reviewed over a ten-year period to determine where to target resources, educational workshops and other messaging. Belcher et al (2020), found ankle and knee injuries to be the most frequent and costly, which is supported by similar research (Downs et al., 2021; Joesph, et al., 2018; Pilay and Frantz, 2012). Belcher et al., (2020) also showed that ankle and knee injury numbers had the biggest increase in 10-19-year-olds over the 10-year period. Whereas injuries in 20-24-year-olds represented the highest cost and continued at a higher rate than in younger players. Finally, the research also indicated spikes in injury likely associated with intense periods of trialling and tournament play in youth players (Belcher et al., 2020). Therefore, the resource content was initially based on reducing ankle and knee injury within the 10-19-year-old group, with a particular focus on preparing them for the season and tournaments. Targeting IPP workshops at developing the knowledge of coaches and physical education teachers, that worked within the youth age groups above, was agreed to be the most appropriate plan. It has been suggested that those training the players should be the initial target of IPP education, as they are most likely to implement the programme and encourage players to adopt the exercises (McGlashin et al., 2018; Richmond et al., 2020; Saunders et al., 2010).

Additionally, it was decided that it would be easier to influence the school age competitive netball system, than the more social/recreational 20-24-year-olds netball scene. School age netball players have a more structured regular competition season and training schedule, which allowed easier infiltration of the NIPP educational information throughout the system (Donaldson et al., 2017; Fulcher et al., 2018; Richmond et al., 2020). This research has also initiated discussions with NNZ around the potential to develop a national injury sport specific database. Though, currently the national injury database appears to be viewed as low priority for NNZ, although this is continually under review (NNZ Poipoia policy, 2020).

After completing the initial implementation planning and epidemiological research discussed above, the collaborative group identified two priority areas for resource and educational development, 'Smart movement' and 'Smart Warm-up". The NetballSmart dynamic warm-up (NSDW) a modified version of the FIFA 11+ warm-up, was one of the first practical resources implemented through the NIPP. The original FIFA 11+ was created by an international group of experts to reduce football injury, however as the physical demands of netball differ to those of football the modified NSDW was created (McKenzie et al., 2019). The NSDW has an increased emphasis on jump-landing technique and control of fast decelerating movements, to better prepare players for the game and improve control of high injury risk movements (McKenzie et al., 2020; Root et al., 2015; Stuelcken et al., 2013). An example of this was adding a Romanian dead-lift exercise as an alternative to the Nordic hamstrings to active ACL agonist muscles, believing it could better replicate movements in the game (Fulcher et al., 2018). IPPs that include trunk stabilisation, posterior chain muscle (hamstring, gluteal, gastrocnemius) strengthening, plyometric exercises and balance have been shown to be successful at reducing injury (Baldon Rde et al., 2014; Emery et al., 2015; Waldén et al., 2012). Unfortunately, the collaborative group reported back that the NSDW (Appendix II) was not getting the traction they hoped within the community. Players and coaches found it too long as it interfered with training time, had too many sets/reps for young players and was boring (McKenzie et al., 2020; O'Brien et al., 2017b; Saunders et al., 2010). To alleviate some of these barriers to adoption, the collaborative group decided there was a need to adapt the NSDW and created a shortened warm-up called the Power warm-up (PWU) (Appendix III). The PWU still contained exercise components that develop general physical abilities, e.g., balance, landing skills, deceleration control, power and plyometrics. In retaining some of these recommended generalised whole-body neuromuscular exercises, it was anticipated that the PWU would remain effective at decreasing injury risk and potentially demonstrate some performance improvements (Faude et al., 2017; Hadzovic et al., 2020; Mugele et al., 2018).

To disseminate the NIPP messaging, as well as the NSDW/PWU educational workshops amongst the greater netball community a focused social media and branding plan was developed. A bright recognisable colour (Orange) was chosen to brand all merchandise, and written content for the programme. This made the resources produced by the NIPP more distinctive (McGlashin et al., 2018; Rogers, 2002; Rosenstock., 1988). The website design and social media plan was initiated, utilising a first group of ambassadors (highly respected players and coaches) to further spread the NIPP messaging. Previous research has identified this is an essential part of dissemination process, as key stakeholders want to receive IPP information/education from a variety of accessible sources that are endorsed by people they admire (Faude et al., 2017; Rogers, 2002; Storey et al., 2008). Videos of the NSDW and PWU warm-up exercises using ambassadors were added to the website and social media videos showing the importance of undertaking the NIPP to reduce injury and be physically prepared for netball were placed on NSO and RSO websites.

The final steps were to evaluate the programmes' first year of implementation, which was done through discussion and informal focus groups, lead-by and within the collaborative group. The feedback highlighted a greater need to investigate the mechanism behind serious knee (in particular ACL) injury and the development of a specific landing skills resource/workshop. This was supported by previous studies that highlighted that jump/landing motions were the most likely mechanism of knee injury in netball (Downs et al., 2020; Flood & Harrison, 2009; Steulcken et al., 2016). Due to the findings of Belcher et al, (2020) that indicated significant spikes in school-age netball players at pre-season and prior to tournaments, the review groups also deemed it important to develop some pre-season and strengthening preparation resources in the following year.

Year Two: Evolving the programme resources through research.

For the second year of the programme the collaborative group in collaboration with ACC (the financier) prioritised investigation of the mechanism of ACL injury. Recent research reported a 120% increase in ACL reconstructions amongst females aged 15–19 years in all sports in New Zealand in the last decade (Sutherland et al., 2019). Netball was identified as a sport with a high rate of ACL injury counts and cost to the ACC (King et al., 2019). It therefore seemed pertinent to focus the development of some of the new NIPP resources and educational workshops on reducing this injury. This process started with expanding the collaborative group to include an expert ACL injury group, which included two accredited physiotherapists (Physiotherapy New Zealand), one orthopaedic surgeon with extensive experience of ACL injury, one retired international player/high-level netball coach and one high performance netball strength and conditioning coach. This expert group communicated regularly to discuss research in the area and how the findings could be integrated into NIPP resources and educational workshops. The groups' main role was to contribute to the systematic analysis of ACL injury videos occurring during televised competitive games sustained during the Australian and New Zealand (NZ) Championship or NZ international netball competitions (January 2008 and October

2019). This process started in the second year, but final analysis was completed in the third year of the programme. The results identified several key areas coaches should focus on in their training. Firstly, coach their players on targeted landing technique training, as 86% of ACL injuries reviewed came after decelerating from a jump/landing movement. The instructions to players should focus on controlling deceleration from jumping movements, aiming for a shoulder-width apart forefoot landing position, > 30^o knees flexion and their centre of mass (COM) centred over their toes (Boden et al., 2010; Hopper et al., 2017; Wright et al., 2000). Secondly, coaches should give specific instruction for players to bring their whole body around into the direction of their next pass and secure the ball in a safe neutral chest position on landing rather than simply turning their head to look for the next pass. Many of the injured players (76%) had turned their head 45-90^o away from their injured knee on landing. Another biomechanical risk factor identified was the final position the ball was placed after receiving an offensive pass. In 57% of the injury cases players caught or reached for an offensive pass with arms held high before lowering the ball (pelvis height or lower), at the time of the injury. The most common action was to bring the ball low and over the injured knee. Finally, incorporating challenges to players balance and their ability to cope with perturbation, may also be beneficial. In 33% of the cases players underwent some form of perturbation in mid-air or on the ground, which likely affected their trunk position control and balance. Similarly, 52% of the players had their COM too posterior on landing or when performing a cutting motion (Song et al., 2021; Yom et al., 2014).

The findings of the video analysis were added to the implications from previous ACL injury research to help design the information and exercise content of the NIPP 'Landing Skill Development' (LSD) resource. This new resource was the principal focus of the promotion plan in the second year of the NIPP that identified and educated coaches/players on improving a specific skill (jump/landing) linked to an injury mechanism. Previously IPP's in NZ had largely only focused on utilising a neuromuscular warm-up programmes (the adapted FIFA 11) to reduce injuries within various sports (Fulcher et al., 2018). A social media and promotional plan were also designed around this resource. Videos with a voice over from a respected netball broadcaster was developed and placed on the newly branded website. The website was then launched with LSD as one of the main banner stories to encourage the public to review the resource. A professional player's personal story of their ACL injury was also recorded, with a message highlighting the importance of jump/landing training and the research that supported the LSD programme design (McGlashan et al., 2018; Storey et al., 2008). The findings of the research were also added to the educational instructions given to coaches when they were running the NSDW or PWU, highlighting the importance of good landing technique right at the start of the training session and throughout. Special emphasis was made for the first-time on receiving the ball in the air and landing successfully in a stable position and with the whole body turned through to face in the direction of their next pass. The coaches were also directed on how to progress the warm-up exercises to include some challenges to balance and perturbation.

Beyond the LSD, two further resources were developed to help guide players on preparing their body to meet the demands of netball, especially for pre and early-season when injury levels spike (Belcher et al., 2020). A body-weighted exercise programme and core stability and balance programme were developed, then added to the website. The exercises included in both programmes were derived from reviewing previous research on IPP and NMT programmes that had shown success in reducing injury and increasing performance (Dai et al., 2012; Mehl et al., 2018; Michaelidis &, Koumantakis, 2012) The programmes included trunk stabilisation, core, ACL agonist knee muscle (hamstrings, gluteals, gastrocnemius) strengthening, plyometric exercises and balance, which are thought to contribute to improved knee alignment during landing (Mehl et al., 2018; Petushek et al., 2019; Stickler, Goehring, & Kinne, 2016; Thomas et al., 2017a). Physical copies of the programmes were offered at targeted pre-season school and club IPP educational workshops. Likewise, the programmes were promoted utilising the NIPP ambassadors, through social media releases.

During the second-year annual review one of the research areas identified to explore was whether the new PWU and previous NSDW were effective at improving landing technique and performance measures in a targeted age group (15-18-year-old). This age group had been identified as a priority need for reduction in injury through the research of Belcher et al., (2020), which was published at the end of the second year of the NIPP. Therefore, 12 teams (six different schools) were identified to undertake the research, with each school being randomly allocated to perform either the PWU or NSDW three times weekly, for a 12-week period. Outcome measures included the Landing Error Score System (LESS), peak vertical ground reaction force (GRF) and frontal plane projection angle (FPPA) all analysed from a dropped vertical jump on to a portable force plate. Along with performance outcome measures of isometric mid-thigh pull (IMTP), Y-balance testing, COD 505, vertical jump (VJ) height and horizontal jump (HJ) distance. Both coaches and players underwent a warm-up educational workshop prior to the research, the content of which focused on improving movement and landing skill technique, guided by the initial results of the ACL mechanism of injury research discussed above. Coaches were given extra guidance on how to access online resources to help through the season. Coaches have indicated they are more likely to adhere to IPPs if they have access to resources and are given practical, professionally taught sessions on the exercises (Saunders et al., 2010). The participating schools were recruited and underwent the 12-week research programme through the second year of the NIPP and the results were analyzed in the third year.

Organisation administrators often act as the initial instigators of a community IPP, as they will develop policies to help dissemination, secure economic backing for coaching professional development and publicising/branding the programme. (Dahlström et al, 2014;

Donaldson et al., 2017). A major success of the NIPP in the second year was its integration at an organizational level with the large-scale intermediate school-age tournament AIMS Games. This collaboration meant that all registered netball coaches had to undergo a NIPP educational workshop prior to attending the tournament and be trained on running the PWU with safe movement technique. Additionally, based on feedback identifying a lack of space to perform the PWU, time to perform it was added into the game time allowing all players to warm-up safely on their court before the games began. In practice this meant that when the referee started the game both teams performed the PWU and following this the game commenced. Finally, the NIPP was able to influence tournament organizers to reduce the length of the game, such that the player loading over the week decreased by 25%. These policy changes only occurred due to a mutual understanding and trust that the programme was evidence-based and could meet the demands of the tournament and their participants needs (Dahlström et al, 2014; O'Brien & Finch, 2014). Simultaneously, the NIPP also managed to form relationships with two large netball centers who agreed to also place the PWU into their weekly intermediate and secondary-school game time. They also ran pre-season NIPP educational workshops on performing the PWU safely. Collaborative relationships with organizations allow for a greater dissemination of an IPP to the community, increases awareness and when endorsed often improves adoption (Dahlström et al, 2014; O'Brien & Finch, 2014; Richmond et al., 2020).

Year Three: Evaluating the NIPP and looking to the future.

The collaborative groups focus in the third year was evaluating and analyzing the resources and research project results that had begun in the first two-years and determining implications for current NIPP messaging and future development. This started by collating and analyzing the results of the warm-up intervention research evaluating the effectiveness of the NSDW and PWU in secondary school age netball players. The cumulation of which saw the publishing of "Short and long versions of a 12-week netball specific neuromuscular warm-up improves landing technique in youth netballers". The conclusion of this study showed that both NSDW and PWU improved landing technique measures (LESS, GRF, FPPA), but neither was significantly more effective than the other. Therefore, the recommendation was that dependent on their environment and time demands, coaches should consider implementing one of the two warm-ups in their netball programmes (Belcher et al., 2021). A second purpose of the study was to look more specifically at performance outcomes as a result of completing the two warm-ups. Significant improvements were found in Y-balance and IMTP (strength) for both warm-up groups, and the NSDW also enhanced 505 COD performance. There was however no significant improvement in VJ and HJ for either warm-up. This again led to the recommendation that either warm-up could be utilized by coaches, but they may benefit from adding further COD, horizontal and vertical jump exercises to either their warm-up or skills training sessions. These results helped to validate the use of PWU and NSDW for many in the netball community, whilst encouraging coaches to use the NIPP LSD resource to further increase jump performance and landing technique.

The expert ACL research group also finalized their systematic video analysis of ACL injuries in elite netball players in this third year. The initial results had been used to guide the LSD resource and promote the importance of specific landing technique training for coaches and players. One of the findings from the analysis was that players were jumping to receive a pass high in the air then opting to bring the ball low, which could cause compressive abduction and rotational knee moments which may increase ACL injury risk (Song et al., 2021; Quatman et al., 2010). It was decided in the third year to take this information and use bright orange gloves as a new training tool in young players. It was thought that these helped young players (NZ School Years1-8) visualize catching the ball at chest height in a stable position and recognize that if they could no longer see the bright gloves, they had dropped the ball too low or away from their body. It was hoped that this external visual cue would help players learn stable landing positions with the ball (Gokeler et al., 2018). This initiative along with presentation of findings from the expert ACL research group to selected sports organization and coaching groups nationally and internationally in the third year, further legitimized the NIPP messaging. This subsequently resulted in an increase in recognition and adoption of the NIPP. The Sports NZ Voice of Participant (VOP) is a national survey sent to those participating in community sport, offering an opportunity to give their views on how their sport is administered and performed. The VOP netball population in 2020 reported utilising the NSDWU/PWU 64% of the time prior to training and 66% prior to game play. This is an improvement on the results of 2017, which was 50% and 51% respectively.

Another positive result identified by the NIPP collaboration group was the 3501 less injury claims at the year-end of 2019, when compared to year-end 2017. The year-end injury counts had reduced even further by approximately 1000 injuries in 2020, when compared to 2019. Additionally, in terms of injuries specifically tracked by the ACC between 2016 to 2020 there was a 11% decrease in fractures and dislocations and a 13% decrease in soft tissue injuries. Probably most notable there was a 9% decrease in ACL reconstruction (ACC Netball injury data 2020). These injury statistics however do include the anomaly Covid-19 year of 2020, where participation in sport was greatly affected, with much community sport being cancelled. It is understandable therefore, that netball related injuries would be reduced considerably in the year 2020, as there was a significant reduction in competition exposure hours. Therefore, the inclusion of the 2020 injury data may have resulted in the reduction in injuries being overestimated. Another consideration is that there has been a growing argument for conservative treatment of ACL injury over surgical reconstruction, which subsequently may have seen a reduction in the percentage of ACL reconstructions seen over the three-years (Krause et al., 2018; Tsoukas, Fotopoulos, Basdekis, & Makridis, 2016). Finally, the NIPP financier ACC reported an

NZD$4.10 return on investment for each invested dollar into the programme's implementation and approximate saving of NZD$16million over the three-year funded period. Due to the reduced injury counts, reduction in financial cost to ACC and the increased signs of adoption, the NIPP has been funded (NZD $3.6 million) for a further 3 years by ACC.

Future directions for the programme

There are plans to publish two further research papers in the 4th year of the programme:

- "Performance ability improves in young female netball players after using netball specific warm-ups." This will report on the performance outcomes of the NSDW and PWU comparison study initiated in the second year of the programme.

- "A systematic video analysis of 21 anterior cruciate ligament injuries in elite netball players during games." This will report on the results of the NIPP ACL research groups findings from the systematic review of videoed ACL injuries described above.

It is hoped that further publication of the research undertaken as part of the NIPP, will help to increase the visibility and legitimacy of the messaging, subsequently achieving greater adoption.

The focus for the NIPP collaborative group over the next few years will be to investigate how best to implement the programme within the social and indoor netball community. As the results of Belcher et al., (2020) showed 20-24-year-old netball players still have the highest rate of knee injury and remain the greatest cost to the ACC. These players are often social recreational players. Thus, they rarely undergo regular training routines or a consistent structured season which makes integrating and publicizing the NIPP within their teams difficult. Focus groups and semi-structured interviews with organization personnel that run the competitions and players on how best to implement the NIPP will be beneficial in the future.

Conclusion

In conclusion the NIPP used research to first create a set of real-world guidelines for the implementation process, that could be followed annually and used to direct programme development. This was achieved by putting together a multi-disciplinary collaborative group, which contained individuals from various recognized stakeholders. The collaborative group then identified areas for targeted research, that could best inform the direction of the programme and/or improve the content design of the educational IP workshops. Several studies were undertaken to explore which body areas were most at risk of injury in netball and possible mechanisms of injury. Research also indicated which age groups within the netball community or time-periods in the season to target both the design of IPP resources and educational workshops. The effectiveness of the two most prominent IPP resources the NSDW and PWU was investigated, providing evidence to support the use of the warm-ups in the netball community. Whilst also identifying the warm-ups shortcomings and offering suggestions of which exercises coaches should target in their training sessions if they wished to reduce injury risk or improve performance further in their players. The evidence-based resources and educational workshops created over the initial three-years of the programme have contributed to the success for the programme and the support of the main financier to invest for a further three-years.

CHAPTER EIGHT: DISCUSSION AND CONCLUSION

Netball is a popular sport worldwide (Hetherington et al.), including in New Zealand where the memebership base is predominately between 10-19-years of age (NNZ affilitated memeber stats). The game requires a range of explosive anaerobic movements including repeated sprints, changes of direction (COD) or cutting manoeuvres and jump-landing (McManus et al., 2006; Thomas et al., 2017b). Moreover, to avoid violating the unique rule of no-stepping whilst in possession of the ball, players must rapidly decelerate during these tasks (Fox et al., 2013; McManus et al., 2006; Otago, 2004). Poor technique during these movements has been reported to contribute to injury, particularly to the lower extremity (Bates et al., 2013; Hewett et al., 2010; Myer et al., 2009; Song et al., 2021). Netball has a high incidence of injury, particularly to the ankle and knee (Belcher et al., 2020; Downs et al., 2021; McManus et al.,200s). Anterior Cruciate Ligament (ACL) rupture is of particular concern for netball in-terms of time lost to play (Downs et al., 2021; Flood & Harrison., 2009; Hopper et al., 1995), risk for early retirement (Otago & Peake, 2007) and associated long-term functional impairments and disabilities (Lohmander et al., 2007; Øiestad, Engebretsen, Storheim, & Risberg, 2009).

With ankle and knee injuries becoming more frequent and costly in netball, the Accident Compensation Corporation (ACC) (a no-fault national insurance system) have choosen to focus on injury prevention strategies. ACC recently partnered with Netball New Zealand (NNZ) in a three-year funded project to create the NetballSmart injury prevention programme (NIPP). The main objective was to decrease serious injuries (ankle and knee) in Netball players and develop physically capable competent movers (PCCM), who can cope with the demands of the game. A collaborative NIPP advisory group was formed which included key stakeholders NNZ, regional sports organisations (RSOs) (5 national netball zones and their centres), schools and clubs. This collaborative team identified key principal areas of focus for the programme. Two priority areas for the programme were 'Smart movement' and 'Smart Warm-up". The NIPP 'Smart movement' resources and educational programmes focused on improving technique in fundamental netball movements associated with performance and injury risk (jump-landing, COD, stopping/decelerating) (Hewett et al., 2010; Song et al., 2021; Steulcken et al., 2016). The 'Smart Warm-up' project integrated the various warm-up resources across the NNZ coaching education framework and utilised NetballSmart Development Officers (NDOs) to teach coaches how to effectively use the warm-up as an injury prevention programme (IPP).

Given the limited implementation success of many IPPs in real-world sports environments, investigating factors impacting the design and implementation of New Zealand's NIPP was essential. This thesis explored how best to develop a real-wrold guide for implemementation of the NIPP over the three-year funding period (*Chapter two*). A series of studies were conducted to identify critical audience groups for programme delivery, guide education workshop content and develop real-world practical advice for coaches (*Chapters three & four*) and evaluate the effectiveness of two NIPP warm-up protocols (*Chapters five & six*). Finally a commentry was provided on the successful translation of these study findings into the real-world implementation of the NIPP programnme, (*Chapter seven*).

Key considerations for the successful implementation of national injury prevention programmes

A narrative review identified four common themes regarding barriers and facilitators to successful implementation and maintenance of IPP's.

The first theme "The importance of collaboration" discusses the power that shared ownership creates when getting stakeholders to advocate a programme. The second theme "The Importance of key stakeholders" recognized the importance of identifying key implementors that drive the planning, creation, adoption and preservation of a successful IPP. The third theme "relevant content' discusses the importance of using up-to-date empirical evidence gathered from a wide range of sources when designing the programme's resource and educational workshop content. The last theme "Implementation" looks at the importance of support and feedback being offered to key stakeholders throughout the programme's entirety.

Based on these themes, a real-world guide to overcome barriers to implementation and maxmise dissemination was proposed: **Step 1**: Engage a multi-disciplinary collaborative IPP design group, containing all key stakeholders and research personnel. *The commentary (Chapter seven) indicates how this step was utilized in the NIPP implementation plan.* **Step 2**: Undertake and review empirical research gathered from a range of research areas/fields. *This provided the rationale for performing the studies in Chapters three and four of this thesis*. **Step 3**: Develop programme resources in a variety of formats, including video, website, infographics, workshop booklets. *Findings from Chapter four helped develop resource content and information on coaching tips for educational workshops given as part of the NIPP. The coaching tips were also included in the coach and player pre-intervention workshops for the warm-up effectiveness studies in chapters five & six.* **Step 4**: Design a dissemination plan, focusing on promotional advertising through social media, television adverts and written releases. *The commentary (Chapter seven) indicates how this step was utilized in the NIPP implementation plan* **Step 5**: Offer support systems for stakeholders to give feedback on IPP performance and adaptations to better suit their teams needs and values. *The commentary (Chapter seven) indicates how this step was utilized in the NIPP implementation plan. Feedback support was also offered to the coaches during the studies in chapters five & six, to help build their self-efficacy to run the programme and subsequently increase compliance.* **Step 6**: Test the feasibility and adoption of the IPP resources and messaging by gathering feedback from the netball community on the IPP effectiveness. *The commentary (Chapter seven) discusses how this step was utilized in the NIPP implementation plan. Chapters five & six gathered direct evidence on whether two key NIPP resources are effective.* These steps acted as the underlying implementation plan used in the first three-years of the funded NIPP and will guide future developments to the programme.

Undertaking empirical research to develop the programme and guide a promotional dissemination plan.

A critical step in the growth of an IPP is to gather empirical evidence identifying key at risk body areas and whether seasonal spikes in injury exits. All of which allows an IPP to target the correct audience for their resource and education workshop development. *Chapter three* reviewed counts and rates of netball ankle and knee injuries in NZ over a 10-year period, with a focus on seasonal changes and age group differences. This research was undertaken in-part to satisfy the recommendations of **Step 2** in the conclusion of the narrative review undertaken in *chapter two*, as well as furthering refine the NIPP implementation plan. This epidemiological study utilised ACC injury data which is considerably more robust than figures sourced from many other countries and was collected over a longer time than any previously published netball injury data. The results of *chapter three* allowed a targeted approach not only for the creation of NIPP programme information/exercise content but offered a more guided approach to promotional dissemination. The results of *chapter three* gave an indication of participation age range to be utilised in the studies exploring the effectiveness of the two warm-up programmes in *chapters five & six*. *Chapter three* also identified injury count and cost as important measures of IPP success, discussed further in the commentary (*chapter seven*) of this thesis. Finally, the seasonal changes in injury identified guided some of the NIPP educational workshop content, tackling the possible injury risk effects high-intensity periods of competition may have on school age netball players.

10-19-year-olds showed large increases in injury between 2008 to 2017. One explanation for increased injury numbers in this group is the suggestion that female's post-puberty show rapidly changing physiological growth developments and hormonal changes that can lead to reduced lower extremity neuromuscular control when landing (Hewett et al., 2006; McManus et al., 2006). Therefore, an IPP targeted towards the 10-19-year-old age group would benefit from focusing on educating players to improve motor control and landing technique prior to and throughout maturation (Root et al., 2015). The increased exposure to high-intensity game demands, from participating in several teams (school, club and representative), may also be a reason this age group have greater injury counts (Caparrós et al., 2016). In the last few decades, the adolescent sport experience has been driven towards professionalisation, intensified training, with greater competition volume and frequency from an early age (Blagrove et al., 2017). Perhaps these alterations in behaviour and attitude in youth sport over the last few decades may to some extent have caused the increased injury counts in 10-19-year-olds in NZ (Bergeron et al., 2015; Rogers et al., 2015).

20-24-year-olds had the highest mean injury rate over the ten-years. At the age of 18+ years, many netballers in NZ stop playing structured competitive games and instead participate in more unstructured social netball competitions. The unstructured nature of this form of netball can mean players are more likely to forgo training and warm-up preparation. The older age groups may also have suffered previous injuries when they were younger, placing them at greater risk of injury in their present season (Mather et al., 2013). Thus, it would seem prudent for a national IPP to also target this group for education on conditioning and preparing their bodies for game demands (King et al., 2019). Another reason 20-24-year-olds are an important group to consider is that they create the largest financial burden to ACC, for example they cost $182,406/1000 members in 2017 for all lower-extremity injuries.

Analysis of data across seasons indicated the start of the season (March to May) has the highest incidence of injury for the youth/adolescent groups. During this time-period, many school age students are undertaking multiple team selection trials and games for club, school and representative netball teams. Many players may have gone from not playing or training for netball due to participation in other sports codes or being out of season, to high intensity game play in the hopes of selection in one or more teams. The second spike in injury counts occurred when training typically increases for national intermediate and secondary school tournaments. Spikes in acute high intensity workload, such as tournaments or when trialling for several teams have been shown to increase injury risk, due largely to increased exposure of the player to game fatigue and competition conditions (Blagrove et al., 2017; Hopper et al., 1995; Talpey, 2015). The seasonal spikes in injury in the younger age groups could potentially be mitigated via changes to the structure of the season and an IPP emphasising education of players and schools on preparing for the season and/or reducing the spikes in load caused by trialling (Hopper et al., 2017; Thomas et al., 2017b).

Netball has previously been identified as a sport with a high rate of ACL injury counts and cost to the ACC (King et al., 2019). Sutherland et al., (2019) also reported a 120% increase in ACL reconstructions amongst females aged 15–19 years in all sports in NZ in the last decade. With the burden of cost and long-term consequences ACL injury has on netball players the NIPP ACL advisory group recognised the need to further understand the mechanism, behaviours and events surrounding the occurrence of this injury. The ACL advisory group consisted of 5 experts (two Physiotherapists, an Orthopaedic surgeon, retired high performance player/coach and a strength and conditioing coach). *Chapter four* systematically analysed 21 ACL injuries which occured during televised Australia and New Zealand (ANZ) premiership or international netball competitions. The ACL advisory group analysed the videos using a set of agreed critical features. The critical features included information on the game situation (e.g., contact or not with other players) and the player's movement during a 10-second index time interval which contained the supposed time of ACL rupture (e.g. running on to a ball, landing). It also included the player's movement behaviour (e.g., head position or where they moved the ball). This was the first systematic video analysis study to include the position of the head at the time of injury and to discuss in detail the effect ball placement has, alongside other biomecachinal factors, on ACL injury. The commentary in C*hapter seven* discusses, how the findings from the ACL injury video analysis were used to help design the NIPP Landing Skills Development (LSD) resource and eductaional workshop. The findings were also used in the educational coaching/player workshops for the NetballSmart Dynamic Warm-up (NSDW) and Power Warm-up (PWU) programmes. These practical training suggestions were also emphasised in the pre-intervention coaching workshops for the players and coaches in *chapters five & six*. Finally, a coaching product was designed to help discourage young players from catching the ball high and then dropping it low into a potentially risky or untsable position. The young players were asked to wear bright orange gripped gloves and if they could no longer see them in front of them, they had dropped the ball out of a safe stable position. This visual cue was hoped to help young players learn catching skills with greater ease and give some immedaite visual feedback.

The conclusion of *chapter four* showed that most ACL injuries occurred when landing from a jump (81%). A common scenario was identified during which players appeared to be attempting to decelerate their landing motion after receiving a ball pass. They did this by utilising a double-footed and wide base of support (WBOS) action, applying breaking forces through an extended knee and flat-foot position on their injured leg. Often the players were unbalanced on landing with their COM too posterior. In 11 cases the players COM was too far backwards on landing placing them in an unstable position and likely increasing the risk of ACL injury (Hewett et al., 2009; Song et al., 2021). In seven cases a player's upper body was contacted by the opposition prior too/during a jump or whilst grounded which could have further affected their ability to control a stable body position when grounded (Song et al., 2021; Yom et al., 2014; Zazaluk et al., 2007). Ball position also likely plays a part in ACL injury risk. In 12 cases the player jumped to receive a ball high before opting to bring it low (pelvis level or below), whether through habit, to control balance or another reason. The effect of this was to likely increase the compressive abduction and rotation motions through the injured knee (Dempsey et al., 2012; Hewett et al., 2009; Song et al., 2021). Another common pattern (16 cases) was for a player to turn their head 45-90º away from their injury-side. It appears the players chose not to bring their whole body around on landing to face the direction of their next pass but turned their head only, to look instead. This likely caused a segmental counter-rotating force through the injured knee, which was planted into a fixed, extended position (Hewett et al., 2009; Quatman et al., 2010; Song et al., 2021).

From these findings four practical suggestions were made for coaches (and others) to use in training.

1. Coaches (and others) should instruct their players in targeted landing technique training. Instructions should encourage controlled deceleration from jumping movements, aiming for a shoulder-width apart fore-foot landing position, > 30º knees flexion and their COM centered over their toes.
2. Coaches should give specific instruction on receiving the ball and then securing it in a safe close to chest position, as well as bringing the whole body around into the direction of the next pass rather than simply turning the head to look. Coaches should be wary of encouraging their players to look for a quick pass if it places them in a high-risk injury position, especially if they lack the physical capacity (neuromuscular control) to do so (Dos'Santos et al., 2021).
3. Incorporating challenges to players balance and ability to cope with perturbation, may be beneficial.
4. Additional core, pelvic and abdominal strengthening to NMT or IPPs could be beneficial in controlling trunk motion during jump-landing and cutting mechanics. Trunk stabilisation and core exercises should help improve landing balance control (Song et al., 2021; Zazaluk et al., 2007).

Testing the feasibility of NIPP resources.

The step implementation guide devised in *chapter 2* indicated the importance of creating a variety of IPP resources that can meet the needs of the implementors (Step 4), whilst also offering feedback for coaches on how to adapt the resource (Step 5). Step 5 and 6 also shows the importance of gaining feedback on the success and effectiveness of the IPP. With this in-mind the NIPP adapted the first IPP programme resource, the NSDW and created the PWU. The PWU is shorter, due to the removal of some strengthening exercises (e.g core and trunk stabilising exercises). It was designed to address proposed barriers described in *chapter two* of this thesis and those found in other neuromuscular warm-up programmes (Martinez et al., 2017; Saunders et al., 2010). With the removal of some exercises previously shown to reduce injury risk (largely strengthening) there was concern the effectiveness of the warm-up would be lost. The purpose of *chapters five & six* was therefore to follow (Step 6) and evaluate whether the full NSDW and PWU can improve landing technique and performance measures in 15-18-year-old netball players and if one was more effective.

Given the importance of landing technique in reducing lower-limb injury risk in netball, exploring the effectiveness of the two NIPP warm-up programmes at improving these movements was needed (Downs et al., 2021; Hewett et al. 2010; Steulcken et al., 2016). The results of *chapter five* show both warm-ups can improve landing technique measures in youth secondary school netball players. A significant proportion of the content of both warm-up programmes incorporated repeated plyometric jumps, cutting and deceleration exercises challenging knee stability. Thus, the warm-up exercises likely encouraged positive neuromuscular adaptations and dynamic control of the players knee position (Hewett et al., 2010; McManus et al., 2006; Myer et al. 2005). Coaches were directed to encourage internal and external feedback on landing technique, such as 'soft landings' - greater knee and hip flexion, reduced ground reaction force (GRF) landings and avoidance of in-ward knee collapse, whilst maintaining stable body position. The intention of these instructions was to improve players awareness of biomechanically high-risk positions and improve landing technique (Andrieux et al., 2012; Gokeler et al., 2018). There were no significant differences between the two warm-ups except in the outcome of the Landing Error Scoring System (LESS), with the PWU showing greater improvement. This could be because there is diminishing return with plyometric exercises or technique training, where performing one drill is as effective as two or three jumping and running drills. Alternatively, the exercises removed for the PWU ('core exercises', Nordics, some running drills), have little relationship to the studies outcome measures, while the exercise retained in both warm-ups (squats, single and double leg jump/landing exercises) were more closely linked to the measures taken.

As coaches often value gains in performance over injury prevention *Chapter six* discussed whether the NIPP warm-ups could improve performance measures (Joy et al., 2013; Lindbholm et al., 2018; McGlashan et al., 2018). The hope being that if the warm-ups could improve performance, it would encourage coaches to adopt the programme and offer practical coachable advice.

Chapter six showed there was no significant difference between the NSDW or PWU for any of the performance measures. Significant improvements were found in Y-balance and strength (Isometric mid-thigh pull) for both warm-up groups, and the NSDW also enhanced 505 COD performance. Vertical jump (VJ) and horizontal jump (HJ) performance failed to improve for either warm-up. Balance (particularly single leg) and strength are essential physical components of netball, controlling explosive actions (jump-landing, change of direction and deceleration) and protecting the body during unstable positions, improving movement technique (Lindblom et al., 2012; Longo et al., 2012; Mothersole et al., 2013). The improvements in this study are possibly due in-part to the heavy focus on single-leg jump-landing exercises in both warm-ups. Both warm-ups also include single-leg squats and the NSDW includes single-leg balance strengthening. There was concern that the removal of the strengthening specific exercise section from the PWU may limit any potential strength gains. One reason positive results were seen in both warm-up programmes may be due to the remaining exercises. Both warm-ups still included squat and lunge exercises as part of the routine, as well as plyometric vertical and horizontal jumping movements. These movements likely provided enough stimulus to cause strength gains in youth players (Impellizzeria et al., 2013; Thomas et al., 2017b). The reason the longer NSDW may have improved COD, is that the programme content includes a specific section on running exercises that closely replicate the 505 test. The PWU includes less running and does not have a featured COD exercise as compared to the NSDW (Plant and Cut). Therefore, the COD training stimulus in the PWU was somewhat less than that of the NSDW. Unfortunately, neither VJ or HJ improved in either warm-up group. Pre-study education to the coaches emphasised achieving maximal jump height or distance was only truly beneficial to performance, if the landing could be controlled. Perhaps coaching instruction therefore did not offer enough stimulus or emphasis on improving jumping explosive movements over the importance of safe landing. Similarly, testing instructions for both VJ and HJ trials in this study required maximal effort but only within the participants landing capabilities.

The warm-up programmes in these studies were coach led in their own training environment, giving ecological validity to the research. It is unrealistic to expect a school or club at community level to rely on physiotherapists or strength and conditioning coaches to supervise warm-up routines. *Chapter two* indicated many coaches require education on correct exercise technique, understanding of the rationale behind chosen content and an opportunity to access resources and support throughout the program (Bizzini et al., 2013; Saunders et al., 2010). In this study the warm-up interventions were formally introduced with a detailed teaching session covering all the above coaching needs, with an option for feedback throughout the study on exercise progression or adaptation to improve player motivation, whilst maintaining fidelity (Martinez et al., 2017; Saunders et al., 2010; Reis et al., 2013). This likely explains why compliance to the programmes over the 12-week period was so high. Players weekly diaries and attendance records indicated >80% compliance to their warm-up sessions with their study coach. Compliance likely played a large part-in the successful outcomes of both studies and supports the recommendation that coaches have access to a teaching programme on how to use the warm-up programmes, safely and effectively (Andrieux et al., 2012; Gokeler et al., 2018; Martinez et al., 2017). Teaching programmes for coaches should focus on analysing and correcting movement technique in the warm-up, whilst developing the ability to adapt the programme to improve motivation yet retain exercise effectiveness (Belcher et al., 2021). However, as no improvement was seen in HJ or VJ outcomes, consideration of adding extra jump-landing technique exercises to warm-up programmes may be beneficial to coaches/players. Teams may also benefit from considering a strength and conditioning or exercise programme to be added to their training regime outside of the warm-up, further increasing their chance of improving explosive jump and COD motion.

Practical lessons learnt.

The commentry in this thesis discusses how the findings were translated into practical outcomes for the first 3-years of the NIPP. The chapter also makes comment on how the initial implemenation step-process derived in *chapter two* was utilised annually to evlauate the sucesses of the programme and determine priority needs for future development.

This was achieved by putting together a multi-disciplinary collaborative group, which contained individuals from various recognized stakeholders. A key benefit of creating a collaborative group that included organisational administrators was their power to endorse and initigrate the NIPP content throughout multiple-levels of coaching and/or player development frameworks (Brown et al., 2016; Frank et al., 2015; McGlashin et al., 2018). Organisational personell were also able to change policies within the competition setting, so that it was compulsory for coaches to be educated on injury prevention principles and implementation of the PWU. This led to greater visibility and adoption of the NIPP. The large collaborative group also allowed for the NIPP educational workshops to be geographically accessible for implementors in an environment they recognised. As well as adding credence to the programme through the influence of respected NIPP role models or ambassodors throughout the three-years.

The collaborative group then identified areas for targeted research that would offer the greatest direction for the programme or improve the content design of the educational IP workshops. This included the 10-year review of ACC netball injury data, detailed in *chapter three* and the ACL analysis study carried out in *chapter four* of the thesis. The results of these studies guided the creation of the Landing Skills Development (LSD) resource and specific landing technique eductaion througout all the NIPP workshops. Finally, the the NIPP undertook studies to explore the effectiveness of two IPP resources the NSDW and PWU, susbstantiating the outcomes of the warm-ups for the netball community (*Chapters five and six*). The evidence-based resources and educational workshops created from the findings of this targeted resarch, largely contributed to the programmes key successes and the support of the main financier to invest for a further three-years

Limitations

Limitations of this thesis were acknowledged where relevant in each chapter. A summary of these limitations is acknowledged here:

- Narrative review methods can lead to some selection bias when selecting studies to review.
- ACC injury data is subject to policy changes, which can effect the definition, collection standards for injury over-time and does not capture exposure details.
- Due to the confidential nature of the ACC dataset, there was no way to account for multiple injury claims by an individual within the year. Multiple claims by one individual may therefore be present in the dataset, which may cause a small effect to the rate of injury.
- Data gathered through the ACC system is not fully reflective of total incidence of

injuries, as it excludes those who have failed to make an injury entitlement claim

- The systematic video analysis used a relatively small sample size for observation.
- The systematic video analysis only recorded injuries that occurred during televised competitive games, which naturally excluded any developmental or recreational-level players or information on injury mechanism during training scenarios.
- The ACL injury cases in the systematic video analysis were initially identified through investigating print media reports, which may have resulted in some selection bias.
- The exact moment when an ACL tear occurs is hard to accurately determine during video analysis and there are challenges with estimating joint angles
- The observed ACL injury mecahnism was made at one-point in time (suspected moment of ACL tear) and thus other potential intrinsic or extrinsic risk factors that may have contributed to injury were not considered.
- Though the statistical analysis during the NSDW and PWU intervention study did account for the cluster effect of the schools, there is likely some effect experienced by the players being taught by other netball coaches throughout the study period.
- During the studies in *chapters 5 and 6* coaches subjectively reported adherence to the program as taught most of the time, but a few did occasionally add or subtract exercises from the resource. This random effect of individual coaching could have influenced the effect of the neuromuscular training for the individual player.
- There was no true control group in the warm-up studies, instead the NSDW (the existing warm-up) served as a pseudo-control group. This reduced the ability to isolate the effect of the warm-ups on landing technique/performance outcomes, from the potential effect of normal training throughout the season.
- Intra-cluster correlation analysis was not performed as a process of study design. A result of which may have led to an underestimation of the *P*-values and risk of incorrectly narrowing the 95% CI, reducing the precision of the findings. A greater number of school clusters would have improved these findings and allowed more confidence in the statistical outcomes of the study and allow the results to be more generalisable to the netball community. However, as possible confounding baseline variables (height, weight etc.) were stratified for within the design and high compliance was maintained throughout the intervention, the effect of failing to perform intra-cluster correlation would have been dampened.

Future Research Directions

Based on the findings from this thesis, the following suggestions for future research include:

- Ongoing research to utilise the ACC injury database.
- Potential to develop a NNZ central injury database.
- Research to determine the effect of distraction and opposition pressure on landing

technique and subsequent ACL injury risk in females.

- Investigate the effect of educational workshops on programme compliance.
- Focus groups and surveys on how to introduce injury prevention warm-ups and messaging within the social/indoor netball setting.
- Investigate the effect of introducing an injury prevention warm-up to a social netball competition on injury rates.

Conclusion

This thesis demonstrates how the design and implementation of the NIPP has been improved. It was achieved by following a real-world pathway through the research, starting with a narrative review of the literature on IPP implementation. The research clearly identified common themes for barriers and facilitating factors that affect implementation of an IPP and from these findings a suggested real-world guide for dissemination of the NIPP over the next three -years was derived. The epidemiological review of ten-years of ACC netball injury data., recognized the most at-risk body sites, age groups and seasonal spikes in injury. The NIPP used these results to target the design and release of their educational and exercise programme content, with the hopes of gaining greater adoption. A systematic analysis of the mechanism and player behavior behind netballs most severe injury (ACL injury) was then performed to offer new insights into practical coaching tips on reducing injury-risk. Subsequently the effectiveness of the two most popular NIPP neuromuscular warm-ups on landing technique and performance outcomes was investigated. These studies showed that neither warm-up was significantly better than the other and both improved all landing technique outcomes and several performance measures. This strengthened the legitimacy of the warm-up programmes within the community, whilst offering suggestions for further training exercises to reduce injury risk and increase performance. Finally, commentary was made on how the research of this thesis was applied in the real-world design and implementation of the NIPP over the first three-years of the programme. Future research building upon the ideas presented in this thesis will further develop understanding, design and adoption of the NIPP in the forthcoming years.

REFERENCES

Adnan, N., Ab Patar, M. N. A., Lee, H., Yamamoto, S., Jong-Young, L., & Mahmud, J. (2018). Biomechanical analysis using Kinovea for sports application. *IOP Conference Series: Materials Science and Engineering, 342*, 012097. doi:10.1088/1757-899X/342/1/012097

Aerts, I., Cumps, E., Verhagen, E., Wuyts, B., Van De Gucht, S., & Meeusen, R. (2015). The effect of a 3-month prevention program on the jump-landing technique in basketball: a randomized controlled trial. *Journal of Sport Rehabilitation, 24*(1), 21-30. doi:10.1123/jsr.2013-0099

Ageberg, E., Bunke, S., Lucander, K., Nilsen, P., & Donaldson, A. (2019). Facilitators to support the implementation of injury prevention training in youth handball: A concept mapping approach. *Scandinavian Journal of Medicine and Science in Sports, 29*(2), 275-285. doi:10.1111/sms.13323

Al Attar, W. S. A., Soomro, N., Pappas, E., Sinclair, P. J., & Sanders, R. H. (2017). Adding a post-training FIFA 11+ exercise program to the pre-training FIFA 11+ injury prevention program reduces injury rates among male amateur soccer players: a cluster-randomised trial. *Journal of Physiotherapy, 63*(4), 235-242. doi:10.1016/j.jphys.2017.08.004

Åman, M., Forssblad, M., & Larsén, K. (2018). Incidence and body location of reported acute sport injuries in seven sports using a national insurance database. *Scandinavian Journal of Medicine and Science in Sports, 28*(3), 1147-1158. doi:10.1111/sms.12956

Andrieux, M., Danna, J., & Thon, B. (2012). Self-control of task difficulty during training enhances motor learning of a complex coincidence-anticipation task. *Research Quarterly for Exercise and Sport, 83*(1), 27-35. doi:10.1080/02701367.2012.10599822

Attenborough, A. S., Sinclair, P. J., Sharp, T., Greene, A., Stuelcken, M., Smith, R. M., & Hiller, C. E. (2017). The identification of risk factors for ankle sprains sustained during netball participation. *Physical Therapy in Sport, 23*, 31-36. doi:10.1016/j.ptsp.2016.06.009

Ayala, F., Pomares-Noguera, C., Robles-Palazón, F. J., Del Pilar García-Vaquero, M., Ruiz-Pérez, I., Hernández-Sánchez, S., & De Ste Croix, M. (2017). Training effects of the fifa 11+ and harmoknee on several neuromuscular parameters of physical performance measures. *International Journal of Sports Medicine, 38*(4), 278-289. doi:10.1055/s-0042-121260

Bahr, R., Thorborg, K., & Ekstrand, J. (2015). Evidence-based hamstring injury prevention is not adopted by the majority of Champions League or Norwegian Premier League football teams: the Nordic Hamstring survey. *British Journal of Sports Medicine, 49*(22), 1466-1471. doi:10.1136/bjsports-2015-094826

Bailey, J. A., Gastin, P. B., Mackey, L., & Dwyer, D. B. (2017). The player load associated with typical activities in elite netball. *International Journal of Sports Physiology and Performance, 12*(9), 1218-1223. doi:10.1123/ijspp.2016-0378

Baldon Rde, M., Serrão, F. V., Scattone Silva, R., & Piva, S. R. (2014). Effects of functional stabilization training on pain, function, and lower extremity biomechanics in women with patellofemoral pain: a randomized clinical trial. *Journal of Orthopeadic Sports Physical Therapy, 44*(4), 240-251, a241-a248. doi:10.2519/jospt.2014.4940

Barber-Westin, S. D., Noyes, F. R., & Galloway, M. (2006). Jump-land characteristics and muscle strength development in young athletes: a gender comparison of 1140 athletes 9 to 17 years of age. *American Journal of Sports Medicine, 34*(3), 375-384. doi:10.1177/0363546505281242

Barber, O. R., Thomas, C., Jones, P. A., McMahon, J. J., & Comfort, P. (2016). Reliability of the 505 change-of-direction test in netball players. *International Journal of Sports Physiolology and Performance, 11*(3), 377-380. doi:10.1123/ijspp.2015-0215

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

Bates, N. A., McPherson, A. L., Berry, J. D., & Hewett, T. E. (2017). Inter- and intra-rater reliability of performance measures collected with a single-camera motion analysis system. *International Journal of Sports Physical Therapy*, *12*(4), 520-526.

Bekker, S., & Clark, A. M. (2016). Bringing complexity to sports injury prevention research: from simplification to explanation. *British Journal of Sports Medicine, 50*(24), 1489-1490. doi:10.1136/bjsports-2016-096457

Bekker, S., Paliadelis, P., & Finch, C. F. (2017). The translation of sports injury prevention and safety promotion knowledge: insights from key intermediary organisations. *Health Research in Policy Systems, 15*(1), 25. doi:10.1186/s12961-017-0189-5

Belanger, L., Burt, D., Callaghan, J., Clifton, S., & Gleberzon, B. J. (2013). Anterior cruciate ligament laxity related to the menstrual cycle: an updated systematic review of the literature. *Journal of the Canadian Chiropractic Association, 57*(1), 76-86.

Belcher, S., Whatman, C., Brughelli, M., & Borotkanics, R. (2020). Ten-year nationwide review of netball ankle and knee injuries in New Zealand. *Journal of Science and Medicine in Sport*, *23*(10), 937-942. doi:https://doi.org/10.1016/j.jsams.2020.04.004

Belcher, S., Whatman, C., Brughelli, M., & Borotkanics, R. (2021). Short and long versions of a 12-week netball specific neuromuscular warm-up improves landing technique in youth netballers. *Phys Ther Sport, 49*, 31-36. doi:10.1016/j.ptsp.2021.01.016

Belcher, S., Whatman, C, &. Brughelli, M (2021). Key considerations for the successful implementation of national injury prevention programmes. *New Zealand Journal of Sports Medicine.* Manuscript accepted for publication.

Bere, T., Flørenes, T. W., Krosshaug, T., Koga, H., Nordsletten, L., Irving, C., . . . Bahr, R. (2011). Mechanisms of anterior cruciate ligament injury in World Cup alpine skiing: a systematic video analysis of 20 cases. *American Journal of Sports Medicine, 39*(7), 1421-1429. doi:10.1177/0363546511405147

Bergeron, M. F., Mountjoy, M., Armstrong, N., Chia, M., Côté, J., Emery, C. A., . . . Engebretsen, L. (2015). International Olympic Committee consensus statement on youth athletic development. *British Journal of Sports Medicine, 49*(13), 843-851. doi:10.1136/bjsports-2015-094962

Bittencourt, N. F., Meeuwisse, W. H., Mendonca, L. D., Nettel-Aguirre, A., Ocarino, J. M., & Fonseca, S. T. (2016). Complex systems approach for sports injuries: moving from risk factor identification to injury pattern recognitionnarrative review and new concept. Br J Sports Med. 50:1309–1314.

Bizzini, M., & Dvorak, J. (2015). FIFA 11+: an effective programme to prevent football injuries in various player groups worldwide-a narrative review. *British Journal of Sports Medicine, 49*(9), 577-579. doi:10.1136/bjsports-2015-094765

Bizzini, M., Impellizzeri, F. M., Dvorak, J., Bortolan, L., Schena, F., Modena, R., & Junge, A. (2013). Physiological and performance responses to the "FIFA 11+" (part 1): is it an appropriate warm-up? *Journal of Sports Science, 31*(13), 1481-1490. doi:10.1080/02640414.2013.802922

Bizzini, M., Junge, A., & Dvorak, J. (2013). Implementation of the FIFA 11+ football warm up program: How to approach and convince the Football associations to invest in prevention. *British Journal of Sports Medicine*, *47*(12), 803-806. doi:10.1136/bjsports-2012-092124

Blagrove, R., Bruinvels, G., & Read, P. (2017). Early sport specialization and intensive training in adolescent female athletes: Risks and recommendations. *Strength and conditioning journal, 39*, 1. doi:10.1519/SSC.0000000000000315

Boden, B. P., Sheehan, F. T., Torg, J. S., & Hewett, T. E. (2010). Noncontact anterior cruciate ligament injuries: mechanisms and risk factors. *J Am Acad Orthop Surg, 18*(9), 520-527. doi:10.5435/00124635-201009000-00003

Bogardus, R. L., Martin, R. J., Richman, A. R., & Kulas, A. S. (2019). Applying the Socio-Ecological Model to barriers to implementation of ACL injury prevention programs: A systematic review. *Journal of Sport Health Science, 8*(1), 8-16. doi:10.1016/j.jshs.2017.11.001

Boling, M., Padua, D., Marshall, S., Guskiewicz, K., Pyne, S., & Beutler, A. (2010). Gender differences in the incidence and prevalence of patellofemoral pain syndrome. *Scandinavian Journal of Medicine and Science in Sports, 20*(5), 725-730. doi:10.1111/j.1600-0838.2009.00996.x

Brady, C. J., Harrison, A. J., & Comyns, T. M. (2020). A review of the reliability of biomechanical variables produced during the isometric mid-thigh pull and isometric squat and the reporting of normative data. *Sports Biomechanics, 19*(1), 1-25. doi.org/10.1080/14763141.2018.1452968

Brenner, J. S. (2007). Overuse injuries, overtraining, and burnout in child and adolescent athletes. *Pediatrics*, *119*(6), 1242-1245. doi:10.1542/peds.2007-0887

Brooks, J. H. M., & Fuller, C. W. (2006). The influence of methodological issues on the results and conclusions from epidemiological studies of sports injuries: Illustrative examples. *Sports Medicine, 36*(6), 459-472.

Brown, J. C., Gardner-Lubbe, S., Lambert, M. I., van Mechelen, W., & Verhagen, E. (2018). Coach-directed education is associated with injury-prevention behaviour in players: an ecological cross-sectional study. *British Journal of Sports Medicine, 52*(15), 989-993. doi:10.1136/bjsports-2016-096757

Brown, J. C., Verhagen, E., Knol, D., Van Mechelen, W., & Lambert, M. I. (2016). The effectiveness of the nationwide BokSmart rugby injury prevention program on catastrophic injury rates. *Scandinavian Journal of Medicine and Science in Sports, 26*(2), 221-225. doi:10.1111/sms.12414

Bruder, A. M., Crossley, K. M., Mosler, A. B., Patterson, B., Haberfield, M., & Donaldson, A. (2020). Co-creation of a sport-specific anterior cruciate ligament injury risk reduction program for women: A concept mapping approach. *Journal of Science and Medicine in Sport, 23*(4), 353-360. doi:10.1016/j.jsams.2019.10.019

Caparrós, T., Alentorn-Geli, E., Myer, G. D., Capdevila, L., Samuelsson, K., Hamilton, B., & Rodas, G. (2016). The relationship of practice exposure and injury rate on game performance and season success in professional male basketball. *Journal of Sports Science and Medicine, 15*(3), 397-402.

Chappell, J. D., & Limpisvasti, O. (2008). Effect of a neuromuscular training program on the kinetics and kinematics of jumping tasks. *American Journal of Sports Medicine, 36*(6), 1081-1086. doi:10.1177/0363546508314425

Chung Chan, D. K., Yeung Lee, A. S., Hagger, M. S., Mok, K.-M., & Yung, P. S.-H. (2017). Social psychological aspects of ACL injury prevention and rehabilitation: An integrated model for behavioral adherence. *Asia-Pacific Journal of Sports Medicine, Arthroscopy, Rehabilitation and Technology, 10*, 17-20. doi:https://doi.org/10.1016/j.asmart.2017.10.001

Cochrane, J. L., Lloyd, D. G., Buttfield, A., Seward, H., & McGivern, J. (2007). Characteristics of anterior cruciate ligament injuries in Australian football. *Journal of Science and Medicine in Sport, 10*(2), 96-104. doi:10.1016/j.jsams.2006.05.015

Critchley, M. L., Davis, D. J., Keener, M. M., Layer, J. S., Wilson, M. A., Zhu, Q., & Dai, B. (2020). The effects of mid-flight whole-body and trunk rotation on landing mechanics: implications for anterior cruciate ligament injuries. *Sports Biomechanics, 19*(4), 421-437. doi:10.1080/14763141.2019.1595704

Dahlström, Ö., Jacobsson, J., & Timpka, T. (2015). Overcoming the organization-practice barrier in sports injury prevention: A nonhierarchical organizational model. *Scandinavian Journal of Medicine and Science in Sports, 25*(4), e414-422. doi:10.1111/sms.12327

Dai, B., Herman, D., Liu, H., Garrett, W. E., & Yu, B. (2012). Prevention of ACL injury, part II: effects of ACL injury prevention programs on neuromuscular risk factors and injury rate. *Research in Sports Medicine, 20*(3-4), 198-222. doi:10.1080/15438627.2012.680987

Davidson, A., & Trewartha, G. (2008). Understanding the physiological demands of netball: A time-motion investigation. *International Journal of Performance Analysis in Sport, 8*, 1-17. doi:10.1080/24748668.2008.11868443

Davis, D. J., Hinshaw, T. J., Critchley, M. L., & Dai, B. (2019). Mid-flight trunk flexion and extension altered segment and lower extremity joint movements and subsequent landing mechanics. *Journal of Science and Medicine in Sport, 22*(8), 955-961. doi:10.1016/j.jsams.2019.03.001

de Villiers, J. E., & Venter, R. E. (2014). Barefoot training improved ankle stability and agility in netball players. *International Journal of Sports Science & Coaching, 9*(3), 485-495. doi:10.1260/1747-9541.9.3.485

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

Della Villa, F., Buckthorpe, M., Grassi, A., Nabiuzzi, A., Tosarelli, F., Zaffagnini, S., & Della Villa, S. (2020). Systematic video analysis of ACL injuries in professional male football (soccer): injury mechanisms, situational patterns and biomechanics study on 134 consecutive cases. *British Journal of Sports Medicine, 54*(23), 1423-1432. doi:10.1136/bjsports-2019-101247

Dempsey, A. R., Elliott, B. C., Munro, B. J., Steele, J. R., & Lloyd, D. G. (2012). Whole body kinematics and knee moments that occur during an overhead catch and landing task in sport. *Clinical Biomechanics, 27*(5), 466-474. doi:10.1016/j.clinbiomech.2011.12.001

DiFiori, J. P., Benjamin, H. J., Brenner, J. S., Gregory, A., Jayanthi, N., Landry, G. L., & Luke, A. (2014). Overuse injuries and burnout in youth sports: a position statement from the American Medical Society for Sports Medicine. *British Journal of Sports Medicine, 48*(4), 287-288. doi:10.1136/bjsports-2013-093299

DiStefano, L. J., Frank, B. S., Root, H. J., & Padua, D. A. (2017). Dissemination and implementation strategies of lower extremity preventive training programs in youth: A clinical review. *Sports Health, 9*(6), 524-531. doi:10.1177/1941738117731732

Donaldson, A., Callaghan, A., Bizzini, M., Jowett, A., Keyzer, P., & Nicholson, M. (2018). Awareness and use of the 11+ injury prevention program among coaches of adolescent female football teams. *International Journal of Sports Science & Coaching, 13*(6), 929-938. doi:10.1177/1747954118787654

Donaldson, A., & Finch, C. F. (2013). Applying implementation science to sports injury prevention. *British Journal of Sports Medicine, 47*(8), 473-475. doi:10.1136/bjsports-2013-092323

Donaldson, A., Lloyd, D. G., Gabbe, B. J., Cook, J., & Finch, C. F. (2017). We have the programme, what next? Planning the implementation of an injury prevention programme. *Injury Prevention, 23*(4), 273-280. doi:10.1136/injuryprev-2015-041737

Donaldson, A., Lloyd, D. G., Gabbe, B. J., Cook, J., Young, W., White, P., & Finch, C. F. (2016). Scientific evidence is just the starting point: A generalizable process for developing sports injury prevention interventions. *Journal of Sport Health Science, 5*(3), 334-341. doi:10.1016/j.jshs.2016.08.003

Dos'Santos, T., Thomas, C., Comfort, P., McMahon, J. J., Jones, P. A., Oakley, N. P., & Young, A. L. (2017). Between-session reliability of isometric mid-thigh pull kinetics and maximal power clean performance in male youth soccer players. *The Journal of Strength & Conditioning Research, 31*, 2748–2757. doi: 10.1519/JSC.0000000000001830

Dos'Santos, T., Thomas, C., McBurnie, A., Comfort, P., & Jones, P. A. (2021). Biomechanical determinants of performance and injury risk during cutting: A performance-injury conflict? *Sports Medicine*. doi:10.1007/s40279-021-01448-3

Downs, C., Snodgrass, S. J., Weerasekara, I., Valkenborghs, S. R., & Callister, R. (2021). Injuries in netball-a systematic review. *Sports Medicine - Open, 7*(1), 3. doi:10.1186/s40798-020-00290-7

Ekegren, C., Gabbe, B. J., & Finch, C. F. (2016). Sports injury surveillance systems: A review of methods and data quality. *Sports Medicine, 46*(1), 49-65. doi:10.1007/s40279-015-0410-z

Emery, C. A. (2007). Considering Cluster Analysis in Sport Medicine and Injury Prevention Research. *Clinical Journal of Sports Medicine, 17*(3), 211-214.

Emery, C. A., Roy, T. O., Whittaker, J. L., Nettel-Aguirre, A., & van Mechelen, W. (2015). Neuromuscular training injury prevention strategies in youth sport: a systematic review and meta-analysis. *British Journal of Sports Medicine, 49*(13), 865-870. doi:10.1136/bjsports-2015-094639

Emery, C. A., van den Berg, C., Richmond, S. A., Palacios-Derflingher, L., McKay, C. D., Doyle-Baker, P. K., . . . Hagel, B. E. (2020). Implementing a junior high school-based programme to reduce sports injuries through neuromuscular training (iSPRINT): a cluster randomised controlled trial (RCT). *British Journal of Sports Medicine, 54*(15), 913-919. doi:10.1136/bjsports-2019-101117

Faude, O., Rössler, R., Petushek, E. J., Roth, R., Zahner, L., & Donath, L. (2017). Neuromuscular adaptations to multimodal injury prevention programs in youth sports: A systematic review with meta-analysis of randomized controlled trials. *Frontier Physiology, 8*, 791. doi:10.3389/fphys.2017.00791

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

Filipa, A., Byrnes, R., Paterno, M. V., Myer, G. D., & Hewett, T. E. (2010). Neuromuscular training improves performance on the star excursion balance test in young female athletes. *Journal of Orthopaedic Sports Physical Therapy, 40*(9), 551-558. doi:10.2519/jospt.2010.3325

Finch, C. F. (2006). A new framework for research leading to sports injury prevention. *Journal of Science and Medicine in Sport, 9*(1-2), 3-9; discussion 10. doi:10.1016/j.jsams.2006.02.009

Finch, C. F., & Cassell, E. (2006). The public health impact of injury during sport and active recreation. *Journal of Science and Medicine in Sport, 9*(6), 490-497. doi:10.1016/j.jsams.2006.03.002

Finch, C. F., Doyle, T. L., Dempsey, A. R., Elliott, B. C., Twomey, D. M., White, P. E., . . . Lloyd, D. G. (2014). What do community football players think about different exercise-training programmes? Implications for the delivery of lower limb injury prevention programmes. *British Journal of Sports Medicine, 48*(8), 702-707. doi:10.1136/bjsports-2013-092816

Flood, L., & Harrison, J. E. (2009). Epidemiology of basketball and netball injuries that resulted in hospital admission in Australia, 2000-2004. *Medical Journal of Australia, 190*(2), 87-90. doi:10.5694/j.1326-5377.2009.tb02285.x

Fox, A., Bonacci, J., McLean, S. G., Spittle, M., & Saunders, N. (2014). What is normal? Female lower limb kinematic profiles during athletic tasks used to examine anterior cruciate ligament injury risk: a systematic review. *Sports Medicine, 44*(6), 815-832. doi:10.1007/s40279-014-0168-8

Fox, A., Spittle, M., Otago, L., & Saunders, N. (2012). An investigation of in-game landings in elite netball: Implications for injury risk. *Journal of Science & Medicine in Sport, 15*, S229-S229.

Fox, A., Spittle, M., Otago, L., & Saunders, N. (2013). Activity profiles of the Australian female netball team players during international competition: implications for training practice. *Journal of Sports Science, 31*(14), 1588-1595. doi:10.1080/02640414.2013.792943

Fox, A., Spittle, M., Otago, L., & Saunders, N. (2014). Offensive agility techniques performed during international netball competition. *International Journal of Sports Science & Coaching, 9*, 543-552. doi:10.1260/1747-9541.9.3.543

Frank, B. S., Register-Mihalik, J., & Padua, D. A. (2015). High levels of coach intent to integrate a ACL injury prevention program into training does not translate to effective implementation. *Journal of Science and Medicine in Sport, 18*(4), 400-406. doi:https://doi.org/10.1016/j.jsams.2014.06.008

Fulcher, M. L., Carlson, I., Mitchell, C., Bizzini, M., & Dvorak, J. (2018). Development and implementation of the ACC SportSmart Warm-up programme: a nationwide sports injury prevention initiative in New Zealand. *British Journal of Sports Medicine, 52*(20), 1334-1338. doi:10.1136/bjsports-2017-098860

Gaglio, B., Shoup, J. A., & Glasgow, R. E. (2013). The RE-AIM framework: a systematic review of use over time. *American Journal of Public Health, 103*(6), e38-46. doi:10.2105/ajph.2013.301299

Gasparyan, A. Y., Ayvazyan, L., Blackmore, H., & Kitas, G. D. (2011). Writing a narrative biomedical review: considerations for authors, peer reviewers, and editors. *Rheumatology International, 31*(11), 1409-1417. doi:10.1007/s00296-011-1999-3

Gianotti, S., Hume, P. A., & Tunstall, H. (2010). Efficacy of injury prevention related coach education within netball and soccer. *Jounal of Science and Medicine in Sport, 13*(1), 32-35. doi:10.1016/j.jsams.2008.07.010

Gokeler, A., Benjaminse, A., Seil, R., Kerkhoffs, G., & Verhagen, E. (2018). Using principles of motor learning to enhance ACL injury prevention programs. *Sports Orthopaedics and Traumatology, 34*(1), 23-30. doi:https://doi.org/10.1016/j.orthtr.2017.12.006

Greenhalgh, T., Thorne, S., & Malterud, K. (2018) Time to challenge the spurious hierarchy of systematic over narrative reviews?. *European Journal of Clinical Investigation, 48*(6), 12931. https://doi.org/10.1111/eci.1293

Greska, E. K., Cortes, N., Van Lunen, B. L., & Oñate, J. A. (2012). A feedback inclusive neuromuscular training program alters frontal plane kinematics. *Journal of Strength and Conditioning Research*, *26*(6), 1609-1619. doi:10.1519/JSC.0b013e318234ebfb

Hadzovic, M., Ilic, P., Lilic, A., & Stankovic, M. (2020). The effects of a knee joint injury prevention program on young female basketball players: A systematic review. *Journal of Anthropology of Sport and Physical Education, 4*(1), 51-56. doi:10.26773/jaspe.200109

Hägglund, M., Atroshi, I., Wagner, P., & Waldén, M. (2013). Superior compliance with a neuromuscular training programme is associated with fewer ACL injuries and fewer acute knee injuries in female adolescent football players: secondary analysis of an RCT. *British Journal of Sports Medicine, 47*(15), 974-979. doi:10.1136/bjsports-2013-092644

Hägglund, M., Waldén, M., Magnusson, H., Kristenson, K., Bengtsson, H., & Ekstrand, J. (2013). Injuries affect team performance negatively in professional football: an 11-year follow-up of the UEFA Champions League injury study. *British Journal of Sports Medicine, 47*(12), 738-742. doi:10.1136/bjsports-2013-092215

Hanson, D. W., Allegrante, J. P., Sleet, D. A., & Finch, C. F. (2014). Research alone is not sufficient to prevent sports injury. *British Journal of Sports Medicine, 48*(8), 682-684. doi:10.1136/bjsports-2012-091434

Hanson, D. W., Finch, C. F., Allegrante, J. P., & Sleet, D. (2012). Closing the gap between injury prevention research and community safety promotion practice: revisiting the public health model. *Public Health Reports, 127*(2), 147-155. doi:10.1177/003335491212700203

Hapeta, J., Palmer, F., Kuroda, Y., & Hermansson, G. (2019). A Kaupapa Māori, culturally progressive, narrative review of literature on sport, ethnicity and inclusion. *Kotuitui: New Zealand Journal Of Social Sciences Online*, *14*(2), 209–229. https://doi-org.ezproxy.aut.ac.nz/10.1080/1177083X.2019.1600558

Herrington, L. (2010). The effects of 4 weeks of jump training on landing knee valgus and crossover hop performance in female basketball players. *Journal of Strength and Conditioning Research, 24*(12), 3427-3432. doi:10.1519/JSC.0b013e3181c1fcd8

Hetherington, S., Hardcastle, S., Visentin, D., & Bird, M.-L. (2009). A kinematic and kinetic case study of a netball shoulder pass. *International Journal of Exercise Science, 2*.

Hewett, T. E., Ford, K. R., Hoogenboom, B. J., & Myer, G. D. (2010). Understanding and preventing acl injuries: Current biomechanical and epidemiologic considerations - update 2010. *North American Journal of Sports Physical Therapy, 5*(4), 234-251.

Hewett, T. E., Ford, K. R., & Myer, G. D. (2006). Anterior cruciate ligament injuries in female athletes: Part 2, a meta-analysis of neuromuscular interventions aimed at injury prevention. *American Journal of Sports Medicine, 34*(3), 490-498. doi:10.1177/0363546505282619

Hewett, T. E., Ford, K. R., Xu, Y. Y., Khoury, J., & Myer, G. D. (2017). Effectiveness of neuromuscular training based on the neuromuscular risk profile. *American Journal of Sports Medicine, 45*(9), 2142-2147.

Hewett, T. E., Torg, J. S., & Boden, B. P. (2009). Video analysis of trunk and knee motion during non-contact anterior cruciate ligament injury in female athletes: lateral trunk and knee abduction motion are combined components of the injury mechanism. *British Journal of Sports Medicine, 43*(6), 417-422. doi:10.1136/bjsm.2009.059162

Hinshaw, T. J., Davis, D. J., Layer, J. S., Zhu, Q., Dai, B., & Wilson, M. A. (2019). Mid-flight lateral trunk bending increased ipsilateral leg loading during landing: a center of mass analysis. *Journal of Sports Sciences, 37*(4), 414-423.

Hopkins, W. G., Marshall, S. W., Batterham, A. M., & Hanin, J. (2009). Progressive statistics for studies in sports medicine and exercise science. *Medicine and Science in Sports and Exercise, 41*(1), 3-13. doi:10.1249/MSS.0b013e31818cb278

Hopper, A. J., Haff, E. E., Joyce, C., Lloyd, R. S., & Haff, G. G. (2017). Neuromuscular training improves lower extremity biomechanics associated with knee injury during landing in 11–13 year old female netball athletes: A randomized control study. *Frontiers in*

Physiology, 8(883). doi:10.3389/fphys.2017.00883
Hopper, D. M. (1997). Somatotype in high performance female netball players may influence player position and the incidence of lower limb and back injuries. *British Journal of Sports Medicine, 31*(3), 197-199. doi:10.1136/bjsm.31.3.197
Hopper, D. M., Elliott, B., & Lalor, J. (1995). A descriptive epidemiology of netball injuries during competition: a five year study. *British Journal of Sports Medicine, 29*(4), 223-228. doi:10.1136/bjsm.29.4.223
Hughes, G., & Dally, N. (2015). Gender difference in lower limb muscle activity during landing and rapid change of direction. *Science & Sports, 30*(3), 163-168.
Hume, P. A., & Steele, J. R. (2000). A preliminary investigation of injury prevention strategies in Netball: are players heeding the advice? *Journal of Science and Medicine in Sport, 3*(4), 406-413. doi:10.1016/s1440-2440(00)80007-9
Impellizzeri, F. M., Bizzini, M., Dvorak, J., Pellegrini, B., Schena, F., & Junge, A. (2013). Physiological and performance responses to the FIFA 11+ (part 2): a randomised controlled trial on the training effects. *Journal of Sports Science, 31*(13), 1491-1502. doi:10.1080/02640414.2013.802926
Jacobs, C. A., Uhl, T. L., Mattacola, C. G., Shapiro, R., & Rayens, W. S. (2007). Hip abductor function and lower extremity landing kinematics: Sex differences. *Journal of Athletic Training (National Athletic Trainers' Association), 42*(1), 76-83.
Johnston, J. T., Mandelbaum, B. R., Schub, D., Rodeo, S. A., Matava, M. J., Silvers-Granelli, H. J., . . . Brophy, R. H. (2018). Video analysis of anterior cruciate ligament tears in professional american football athletes. *American Journal of Sports Medicine, 46*(4), 862-868.
Joseph, C., Naughton, G., & Antcliff, A. (2019). Australian netball injuries in 2016: An overview of insurance data. *Journal of Science and Medicine in Sport, 22*. doi:10.1016/j.jsams.2019.07.016
Joy, E. A., Taylor, J. R., Novak, M. A., Chen, M., Fink, B. P., & Porucznik, C. A. (2013). Factors influencing the implementation of anterior cruciate ligament injury prevention strategies by girls soccer coaches. *Journal of Strength and Conditioning Research, 27*(8), 2263-2269. doi:10.1519/JSC.0b013e31827ef12e
Junge, A., Lamprecht, M., Stamm, H., Hasler, H., Bizzini, M., Tschopp, M., . . . Dvorak, J. (2011). Countrywide campaign to prevent soccer injuries in Swiss amateur players. *American Journal of Sports Medicine, 39*(1), 57-63. doi:10.1177/0363546510377424
Kilding, A. E., Tunstall, H., & Kuzmic, D. (2008). Suitability of fifa's "the 11" training programme for young football players - impact on physical performance. *Journal of Sports Science and Medicine, 7*(3), 320-326.
King, D., Hume, P. A., Hardaker, N., Cummins, C., Gissane, C., & Clark, T. (2019). Sports-related injuries in New Zealand: National Insurance (Accident Compensation Corporation) claims for five sporting codes from 2012 to 2016. *British Journal of Sports Medicine, 53*(16), 1026-1033. doi:10.1136/bjsports-2017-098533
Knowles, S. B., Marshall, S. W., & Guskiewicz, K. M. (2006). Issues in estimating risks and rates in sports injury research. *Journal of Athletic Training (National Athletic Trainers' Association), 41*(2), 207-215.
Koga, H., Nakamae, A., Shima, Y., Iwasa, J., Myklebust, G., Engebretsen, L., . . . Krosshaug, T. (2010). Mechanisms for noncontact anterior cruciate ligament injuries: Knee joint kinematics in 10 injury situations from female team handball and basketball. *American Journal of Sports Medicine, 38*(11), 2218-2225. doi:10.1177/0363546510373570
Kozieł, S. M., & Malina, R. M. (2018). Modified maturity offset prediction equations: Validation in independent longitudinal samples of boys and girls. *Sports Medicine, 48*(1), 221-236. doi:10.1007/s40279-017-0750-y
Krause, M., Freudenthaler, F., Frosch, K. H., Achtnich, A., Petersen, W., & Akoto, R. (2018). Operative versus conservative treatment of anterior cruciate ligament rupture. *Deutsches Ärzteblatt International, 115*(51-52), 855-862. doi:10.3238/arztebl.2018.0855
Krosshaug, I., Nakamae, A., Boden, B. P., Engebretsen, L., Smith, G., Slauterbeck, J. R., . . . Bahr, R. (2007). Mechanisms of anterior cruciate ligament injury in basketball: Video analysis of 39 cases. *American Journal of Sports Medicine, 35*(3), 359-367.
Krosshaug, T., Nakamae, A., Boden, B., Engebretsen, L., Smith, G., Slauterbeck, J., . . . Bahr,

R. (2007). Estimating 3D joint kinematics from video sequences of running and cutting maneuvers--assessing the accuracy of simple visual inspection. *Gait and Posture, 26*(3), 378-385. doi:10.1016/j.gaitpost.2006.10.010

Kuijt, M. T., Inklaar, H., Gouttebarge, V., & Frings-Dresen, M. H. (2012). Knee and ankle osteoarthritis in former elite soccer players: a systematic review of the recent literature. *Journal of Science and Medicine in Sport, 15*(6), 480-487. doi:10.1016/j.jsams.2012.02.008

LaBella, C. R., Huxford, M. R., Grissom, J., Kim, K. Y., Peng, J., & Christoffel, K. K. (2011). Effect of neuromuscular warm-up on injuries in female soccer and basketball athletes in urban public high schools: cluster randomized controlled trial. *Archives of pediatrics & adolescent medicine, 165*(11), 1033-1040. doi:10.1001/archpediatrics.2011.168

Lake, J., Mundy, P., Comfort, P., McMahon, J. J., Suchomel, T. J., & Carden, P. (2018). Concurrent Validity of a Portable Force Plate Using Vertical Jump Force-Time Characteristics. *Journal of applied biomechanics, 34*(5), 410–413. https://doi.org/10.1123/jab.2017-0371

Langeveld, E., Coetzee, D., & Holtzhausen, L. (2012). Epidemiology of injuries in elite south african netball players. *South African Journal for Research in Sport, Physical Education and Recreation, 34*, 83-93.

Lavipour, D. (2011). *Development of a netball specific dynamic balance assessment*. (Thesis for Masters of Philosophy, Auckland University of Technology, New Zealand), https://librarysearch.aut.ac.nz/vufind/Record/b2783440

Lindblom, H., Carlfjord, S., & Hägglund, M. (2018). Adoption and use of an injury prevention exercise program in female football: A qualitative study among coaches. *Scandinavian Journal of Medicine and Science in Sports, 28*(3), 1295-1303. doi:10.1111/sms.13012

Lloyd, R. S., Faigenbaum, A. D., Stone, M. H., Oliver, J. L., Jeffreys, I., Moody, J. A., . . . Myer, G. D. (2014). Position statement on youth resistance training: the 2014 International Consensus. *British Journal of Sports Medicine, 48*(7), 498-505. doi:10.1136/bjsports-2013-092952

Lloyd, R. S., & Oliver, J. L. (2012). The Youth Physical Development Model. *Strength and conditioning journal, 34*, 61-72. doi:10.1519/SSC.0b013e31825760ea

Lohmander, L. S., Englund, P. M., Dahl, L. L., & Roos, E. M. (2007). The long-term consequence of anterior cruciate ligament and meniscus injuries: osteoarthritis. *The American journal of sports medicine, 35*(10), 1756-1769. doi:10.1177/0363546507307396

Longo, U. G., Loppini, M., Berton, A., Marinozzi, A., Maffulli, N., & Denaro, V. (2012). The FIFA 11+ program is effective in preventing injuries in elite male basketball players: a cluster randomized controlled trial. *American Journal of Sports Medicine, 40*(5), 996-1005. doi:10.1177/0363546512438761

Lopes, T. J. A., Simic, M., Myer, G. D., Ford, K. R., Hewett, T. E., & Pappas, E. (2018). The Effects of Injury Prevention Programs on the Biomechanics of Landing Tasks: A Systematic Review With Meta-analysis. *Am J Sports Med, 46*(6), 1492-1499. doi:10.1177/0363546517716930

Lythe, M., & Norton, R. (1992). Rugby league injuries in New Zealand. *New Zealand Journal of Sports Medicine, 20*, 6-7.

Malinzak, R. A., Colby, S. M., Kirkendall, D. T., Yu, B., & Garrett, W. E. (2001). A comparison of knee joint motion patterns between men and women in selected athletic tasks. *Clinical Biomechanics, 16*(5), 438-445. doi:10.1016/S0268-0033(01)00019-5

Martinez, J. C., Mazerolle, S. M., Denegar, C. R., Joseph, M. F., Pagnotta, K. D., Trojian, T. H., & DiStefano, L. J. (2017). Female adolescent athletes' attitudes and perspectives on injury prevention programs. *Journal of Science and Medicine in Sport, 20*(2), 146-151. doi:10.1016/j.jsams.2016.06.009

Mather, R. C., 3rd, Koenig, L., Kocher, M. S., Dall, T. M., Gallo, P., Scott, D. J., . . . Spindler, K. P. (2013). Societal and economic impact of anterior cruciate ligament tears. *Journal of Bone and Joint Surgery of America 95*(19), 1751-1759. doi:10.2106/jbjs.L.01705

Maulder, P. S., & Cronin, J. (2005). Horizontal and vertical jump assessment: reliability, symmetry, discriminative and predictive ability. *Physical Therapy in Sport, 6*(2), 74-82. doi:https://doi.org/10.1016/j.ptsp.2005.01.001

McCambridge, T. M., & Stricker, P. R. (2008). Strength training by children and adolescents. *Pediatrics, 121*(4), 835-840. doi:10.1542/peds.2007-3790

McGlashan, A., Verrinder, G., & Verhagen, E. (2018). Working towards More Effective Implementation, Dissemination and Scale-Up of Lower-Limb Injury-Prevention Programs: Insights from Community Australian Football Coaches. *International Journal of Environmental Research in Public Health, 15*(2). doi:10.3390/ijerph15020351

McKay, C. D., Steffen, K., Romiti, M., Finch, C. F., & Emery, C. A. (2014). The effect of coach and player injury knowledge, attitudes and beliefs on adherence to the FIFA 11+ programme in female youth soccer. *British Journal of Sports Medicine, 48*(17), 1281-1286. doi:10.1136/bjsports-2014-093543

McKenzie, C. R., Whatman, C., Brughelli, M., & Borotkanics, R. (2019). The effect of the NetballSmart Dynamic Warm-up on physical performance in youth netball players. *Physical Therapy in Sport, 37*, 91-98. doi:10.1016/j.ptsp.2019.03.005

McKenzie, C. R., Whatman, C., Brughelli, M, & Cairns, S (2020). An evaluation of the netballsmart dynamic warm-up in youth netball: (a thesis submitted to Auckland University of Technology in fulfilment of the requirements for the degree of Doctor of Philosophy (PhD)) . https://librarysearch.aut.ac.nz/vufind/Record/b2737578

McManus, A., Stevenson, M. R., & Finch, C. F. (2006). Incidence and risk factors for injury in non-elite netball. *Journal of Science and Medicine in Sport, 9*(1), 119-124. doi:https://doi.org/10.1016/j.jsams.2006.03.005

Meeuwisse, T. H. H., Hagel, H. B. & Emery, H. C. (2007). A dynamic model of etiology in sport injury: the recursive nature of risk and causation. *Clinical Journal of Sport Medicine. 17*(3):215–219.

Mehl, J., Diermeier, T., Herbst, E., Imhoff, A. B., Stoffels, T., Zantop, T., . . . Achtnich, A. (2018). Evidence-based concepts for prevention of knee and ACL injuries. 2017 guidelines of the ligament committee of the German Knee Society (DKG). *Archives of Orthopaedic & Trauma Surgery, 138*(1), 51-61.

Michaelidis, M., & Koumantakis, G. A. (2014). Effects of knee injury primary prevention programs on anterior cruciate ligament injury rates in female athletes in different sports: a systematic review. *Physical Therapy in Sport, 15*(3), 200-210. doi:10.1016/j.ptsp.2013.12.002

Mirwald, R. L., Baxter-Jones, A. D., Bailey, D. A., & Beunen, G. P. (2002). An assessment of maturity from anthropometric measurements. *Medicine & Science in Sports & Exercise, 34*(4), 689-694. doi:10.1097/00005768-200204000-00020

Mokhtarzadeh, H., Ewing, K., Janssen, I., Yeow, C.-H., Brown, N., & Lee, P. V. S. (2017). The effect of leg dominance and landing height on ACL loading among female athletes. *Journal of Biomechanics, 60*, 181-187.

Montgomery, C., Withers, D., Moran, C., Blackburn, J., Tierney, G., & Simms, C. (2018). Mechanisms of ACL injury in professional rugby union: A systematic video analysis of 36 cases. *British Journal of Sports Medicine, 52*(15), 994-1001. doi:10.1136/bjsports-2016-096425

Morgan, E. A., Johnson, S. T., Bovbjerg, V. E., & Norcross, M. F. (2017). Associations between player age and club soccer coaches' perceptions of injury risk and lower extremity injury prevention program use. *International Journal of Sports Science & Coaching, 13*(1), 122-128. doi:10.1177/1747954117707480

Morrey, M. A., Stuart, M. J., Smith, A. M., & Wiese-Bjornstal, D. M. (1999). A longitudinal examination of athletes' emotional and cognitive responses to anterior cruciate ligament injury. *Clinical Journal of Sport Medicine, 9*(2), 63-69. doi:10.1097/00042752-199904000-00004

Mothersole, G., Cronin, J., & Harris, N. (2013). Key prerequisite factors influencing landing forces in netball. *Strength and conditioning journal, 35*, 47-54. doi:10.1519/SSC.0b013e318289b79e

Mugele, H., Plummer, A., Steffen, K., Stoll, J., Mayer, F., & Müller, J. (2018). General versus sports-specific injury prevention programs in athletes: A systematic review on the effect on injury rates. *PLOS One, 13*(10), e0205635-e0205635. doi:10.1371/journal.pone.0205635

Murphy, D. F., Connolly, D. A. J., & Beynnon, B. D. (2003). Risk factors for lower extremity

injury: a review of the literature. *British Journal of Sports Medicine, 37*(1), 13-29.
Myer, G. D., Ford, K. R., Divine, J. G., Wall, E. J., Hewett, T. E., & Kahanov, L. (2009). Longitudinal assessment of noncontact anterior cruciate ligament injury risk factors during maturation in a female athlete: A case report. *Journal of Athletic Training, 44*(1), 101-109. doi:10.4085/1062-6050-44.1.101
Myer, G. D., Ford, K. R., Palumbo, J. P., & Hewett, T. E. (2005). Neuromuscular training improves performance and lower-extremity biomechanics in female athletes. *Journal of Strength and Conditioning Research*, *19*(1), 51-60. doi:10.1519/13643.1
Myklebust, G., Skjølberg, A., & Bahr, R. (2013). ACL injury incidence in female handball 10 years after the Norwegian ACL prevention study: important lessons learned. *British Journal of Sports Medicine*, *47*(8), 476-479. doi:10.1136/bjsports-2012-091862
Nessler, T., Denney, L., & Sampley, J. (2017). ACL injury prevention: What does research tell us? *Curr Rev Musculoskelet Med, 10*(3), 281-288. doi:10.1007/s12178-017-9416-5
New Zealand Accident Compensation Corporation. (2018). *Injury Statistics*. [Injury data]. Retrieved from: http://www.acc.co.nz/about-acc/statistics/injury-statistics/index.htm#
New Zealand Accident Compensation Corporation. (2020). Injury Statistics. [Injury data]. Retrieved from: http://www.acc.co.nz/about-acc/statistics/injury-statistics/index.htm#
Netball New Zealand. Rules of netball. http://www.netballnz.co.nz/our-game/rulesof-
netball, (2018). (Accessed 3 March 2018).
Netball New Zealand. Ninety-third annual report (2019). Palo Alto, CA: Issuu. https:// issuu.com/netballnz/docs/nnz_annual_report_-_2019. (Accessed 12 December 2020).
Netball New Zealand. Rules of netball. http://www.netballnz.co.nz/our-game/rulesof-
netball, (2020). (Accessed 12 October 2020).
Netball New Zealand. Poipoia policy (2020). Poipoia_StrategicDocument_NNZ.pdf. (Accessed 20 September 20, 2021).
Norcross, M. F., Johnson, S. T., Bovbjerg, V. E., Koester, M. C., & Hoffman, M. A. (2016). Factors influencing high school coaches' adoption of injury prevention programs. *Journal of Science and Medicine in Sport*, *19*(4), 299-304. doi:10.1016/j.jsams.2015.03.009
Nyland, J., Burden, R., Krupp, R., & Caborn, D. N. (2011). Whole body, long-axis rotational training improves lower extremity neuromuscular control during single leg lateral drop landing and stabilization. *Clinical Biomechanics (Bristol, Avon), 26*(4), 363-370. doi:10.1016/j.clinbiomech.2010.11.021
O'Brien, J., & Finch, C. F. (2014). The implementation of musculoskeletal injury-prevention exercise programmes in team ball sports: a systematic review employing the RE-AIM framework. *Sports Medicine, 44*(9), 1305-1318. doi:10.1007/s40279-014-0208-4
O'Brien, J., Young, W., & Finch, C. F. (2017a). The delivery of injury prevention exercise programmes in professional youth soccer: Comparison to the FIFA 11. *Journal of Science and Medicine in Sport, 20*(1), 26-31. doi:10.1016/j.jsams.2016.05.007
O'Brien, J., Young, W., & Finch, C. F. (2017b). The use and modification of injury prevention exercises by professional youth soccer teams. *Scandinavian Journal of Medicine and Science in Sports, 27*(11), 1337-1346. doi:10.1111/sms.12756
O'Brien, J., Finch, C. F., Pruna, R., & McCall, A. (2019) A new model for injury prevention in team sports: the Team-sport Injury Prevention (TIP) cycle. *Science and Medicine in Football*, *3*(1), 77-80. DOI: 10.1080/24733938.2018.1512752
Øiestad, B. E., Engebretsen, L., Storheim, K., & Risberg, M. A. (2009). Knee osteoarthritis after anterior cruciate ligament injury: a systematic review. *Am J Sports Medicine, 37*(7), 1434-1443. doi:10.1177/0363546509338827
Olsen, O.-E., Myklegust, G., Engebretsen, L., & Bahr, R. (2004). Injury mechanisms for anterior cruciate ligament injuries in team handball: A systematic video analysis. *American Journal of Sports Medicine, 32*(4), 1002-1012.
Otago, L. (2004). Kinetic analysis of landings in netball: is a footwork rule change required to decrease ACL injuries? *Journal of Science & Medicine in Sport, 7*(1), 85-95.
Otago, L., & Peake, J. (2007). The role of insurance data in setting priorities for netball injury prevention strategies. *Journal of Science and Medicine in Sport, 10*(2), 105-109. doi:10.1016/j.jsams.2006.05.016
Padua, D. A., DiStefano, L. J., Beutler, A. I., de la Motte, S. J., DiStefano, M. J., & Marshall, S.

W. (2015). The Landing Error Scoring System as a Screening Tool for an Anterior Cruciate Ligament Injury-Prevention Program in Elite-Youth Soccer Athletes. *Journal of Athletic Training, 50*(6), 589-595.

Padua, D. A., Frank, B., Donaldson, A., de la Motte, S., Cameron, K. L., Beutler, A. I., . . . Marshall, S. W. (2014). Seven steps for developing and implementing a preventive training program: lessons learned from JUMP-ACL and beyond. *Clinical Sports Medicine, 33*(4), 615-632. doi:10.1016/j.csm.2014.06.012

Pappas, E., Zampeli, F., Xergia, S., & Georgoulis, A. (2013). Lessons learned from the last 20 years of ACL-related in vivo-biomechanics research of the knee joint. *Knee Surgery, Sports Traumatology, Arthroscopy, 21*(4), 755-766.

Pardos-Mainer, E., Casajús, J. A., & Gonzalo-Skok, O. (2019). Adolescent female soccer players' soccer-specific warm-up effects on performance and inter-limb asymmetries. *Biology of Sport, 36*(3), 199-207. doi:10.5114/biolsport.2019.85453

Parsons, J. L., Carswell, J., Nwoba, I. M., & Stenberg, H. (2019). Athlete perceptions and physical performance effects of the fifa 11 + program in 9-11 year-old female soccer players: A cluster randomized trial. *International Journal of Sports Physical Therapy, 14*(5), 740-752.

Petushek, E. J., Sugimoto, D., Stoolmiller, M., Smith, G., & Myer, G. D. (2019). Evidence-based best-practice guidelines for preventing anterior cruciate ligament injuries in young female athletes: A systematic review and meta-analysis. *The American journal of sports medicine, 47*(7), 1744-1753. doi:10.1177/0363546518782460

Pfile, K. R., & Curioz, B. (2017). Coach-led prevention programs are effective in reducing anterior cruciate ligament injury risk in female athletes: A number-needed-to-treat analysis. *Scandinavian Journal of Medicine and Science in Sports, 27*(12), 1950-1958. doi:10.1111/sms.12828

Pfile, K. R., Gribble, P. A., Buskirk, G. E., Meserth, S. M., & Pietrosimone, B. G. (2016). Sustained improvements in dynamic balance and landing mechanics after a 6-week neuromuscular training program in college women's basketball players. *Journal of Sport Rehabilitation, 25*(3), 233-240. doi:10.1123/jsr.2014-0323

Pillay, T., & Frantz, J. M. (2012). Injury prevalence of netball players in South Africa: The need for in jury prevention. *South African Journal of Physiotherapy, 68*(3), 7-10. doi:10.4102/sajp.v68i3.17

Podraza, J. T., & White, S. C. (2010). Effect of knee flexion angle on ground reaction forces, knee moments and muscle co-contraction during an impact-like deceleration landing: Implications for the non-contact mechanism of ACL injury. *Knee, 17*(4), 291-295. doi:10.1016/j.knee.2010.02.013

Poulos, R. G., & Donaldson, A. (2012). Is sports safety policy being translated into practice: what can be learnt from the Australian rugby union Mayday procedure? *British Journal of Sports Medicine, 46*(8), 585-590. doi:10.1136/bjsports-2011-090469

Powden, C. J., Dodds, T. K., & Gabriel, E. H. (2019). The reliability of the star excursion balance test and lower quarter y-balance test in healthy adults: a systematic review. The *International Journal of Sports Physical Therapy, 14*(5), 683-694. DOI: 10.26603/ijspt20190683

Powers, C. M. (2010). The influence of abnormal hip mechanics on knee injury: A biomechanical perspective. *Journal of Orthopaedic & Sports Physical Therapy, 40*(2), 42-51. doi:10.2519/jospt.2010.3337

Quatman, C. E., Quatman-Yates, C. C., & Hewett, T. E. (2010). A 'plane' explanation of anterior cruciate ligament injury mechanisms: a systematic review. *Sports Medicine, 40*(9), 729-746. doi:10.2165/11534950-000000000-00000

Rakitzis, A. C., Castagliola, P., & Maravelakis, P. E. (2016). Cumulative sum control charts for monitoring geometrically inflated Poisson processes: An application to infectious disease counts data. *Statistical Methods in Medical Research, 27*(2), 622-641. doi:10.1177/0962280216641985

Rebai, H., Zarrouk, N., Ghroubi, S., Sellami, M., Ayedi, F., Baklouti, S., . . . Elleuch, M. (2012). Long-term basketball playing enhances bone mass and isokinetic muscle strength. *Isokinetics and Exercise Science, 20*, 221-227. doi:10.3233/IES-2012-0463

Reis, I., Rebelo, A., Krustrup, P., & Brito, J. (2013). Performance enhancement effects of

Fédération Internationale de Football Association's "The 11+" injury prevention training program in youth futsal players. *Clinical Journal of Sports Medicine*, *23*(4), 318-320. doi:10.1097/JSM.0b013e318285630e

Renstrom, P., Ljungqvist, A., Arendt, E., Beynnon, B., Fukubayashi, T., Garrett, W., . . . Engebretsen, L. (2008). Non-contact ACL injuries in female athletes: an International Olympic Committee current concepts statement. *British Journal of Sports Medicine*, *42*(6), 394-412. doi:10.1136/bjsm.2008.048934

Richmond, S. A., Donaldson, A., Macpherson, A., Bridel, W., van den Berg, C., Finch, C. F., . . . Emery, C. A. (2020). Facilitators and barriers to the implementation of isprint: A sport injury prevention program in junior high schools. *Clinical Journal of Sports Medicine*, *30*(3), 231-238. doi:10.1097/jsm.0000000000000579

Roe, M., Malone, S., Blake, C., Collins, K., Gissane, C., Buttner, F., Murphy, J. C., & Delahunt, E. (2017). A six stage operational framework for individualising injury risk management in sport. *Injury Epidemiology*, *4*(1):26.

Rogers, E. M. (2002). Diffusion of preventive innovations. *Addictive Behaviour*, *27*(6), 989-993. doi:10.1016/s0306-4603(02)00300-3

Rogers, H., & Cassidy, T. (2015). ‘Quest for success’: The micro-politics associated with the inception and development of a secondary school sport academy. *Asia-Pacific Journal of Health, Sport and Physical Education*, *6*, 1-14. doi:10.1080/18377122.2015.1051267

Root, H., Trojian, T., Martinez, J., Kraemer, W., & DiStefano, L. J. (2015). Landing Technique and Performance in Youth Athletes After a Single Injury-Prevention Program Session. *Journal of Athletic Training*, *50*(11), 1149.

Rosenstock, I. M., Strecher, V. J., & Becker, M. H. (1988). Social learning theory and the Health Belief Model. *Health Education Quarterly*, *15*(2), 175-183. doi:10.1177/109019818801500203

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

Sheehan, F. T., Sipprell, W. H., & Boden, B. P. (2012). Dynamic Sagittal Plane Trunk Control During Anterior Cruciate Ligament Injury. *American Journal of Sports Medicine, 40*(5), 1068-1074. doi:10.1177/0363546512437850

Silva, L. M., Neiva, H. P., Marques, M. C., Izquierdo, M., & Marinho, D. A. (2018). Effects of warm-up, post-warm-up, and re-warm-up strategies on explosive efforts in team sports: A systematic review. *Sports Medicine, 48*(10), 2285-2299. doi:10.1007/s40279-018-0958-5

Smartt, P., & Chalmers, D. (2009). Obstructing the goal? Hospitalisation for netball injury in New Zealand 2000-2005. *The New Zealand medical journal*, *122*, 62-75.

Soligard, T., Nilstad, A., Steffen, K., Myklebust, G., Holme, I., Dvorak, J., . . . Andersen, T. E. (2010). Compliance with a comprehensive warm-up programme to prevent injuries in youth football. *British Journal of Sports Medicine*, *44*(11), 787-793. doi:10.1136/bjsm.2009.070672

Sommerfield, L. M., Harrison, C. B., Whatman, C. S., & Maulder, P. S. (2020). Relationship between strength, athletic performance, and movement skill in adolescent girls. *J Strength Cond Res*. doi:10.1519/jsc.0000000000003512

Song, Y., Li, L., Hughes, G., & Dai, B. (2021). Trunk motion and anterior cruciate ligament injuries: a narrative review of injury videos and controlled jump-landing and cutting tasks. *Sports biomechanics*, 1-19. doi:10.1080/14763141.2021.1877337

Steele, J. R. (1988). *The effect of changes to passing height on the mechanics of landing in netball. Non-technical report III / by Julie R. Steele*. [Canberra]: National Sports Research Centre.

Steffen, K., Bakka, H. M., Myklebust, G., & Bahr, R. (2008). Performance aspects of an injury prevention program: a ten-week intervention in adolescent female football players. *Scandinavian Journal of Medicine and Science in Sports*, *18*(5), 596-604. doi:10.1111/j.1600-0838.2007.00708.x

Steffen, K., Emery, C. A., Romiti, M., Kang, J., Bizzini, M., Dvorak, J., . . . Meeuwisse, W. H. (2013). High adherence to a neuromuscular injury prevention programme (FIFA 11+)

improves functional balance and reduces injury risk in Canadian youth female football players: a cluster randomised trial. *British Journal of Sports Medicine, 47*(12), 794-802. doi:10.1136/bjsports-2012-091886

Stickler, L., Goehring, M., & Kinne, B. (2016). The impact of hip strengthening and/or neuromuscular control on frontal plane knee kinematics and kinetics in females: a systematic review. *Physical Therapy Reviews, 21*, 1-7. doi:10.1080/10833196.2016.1214357

Storey, J., D., Saffitz, G., B., & Rimon, J., G (2008). *Social marketing*. In, Glanz, K., Rimer, B., K., & Viswanath, K. (ed.) *Health behaviour and health education (Vol 4)*. San Francisco: Jossey-Bass, 2008; 435–461.

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

Stuelcken, M., Mellifont, D. B., Gorman, A. D., & Sayers, M. G. (2016). Mechanisms of anterior cruciate ligament injuries in elite women's netball: a systematic video analysis. *Journal of Sports Science, 34*(16), 1516-1522. doi:10.1080/02640414.2015.1121285

Sugimoto, D., Mattacola, C. G., Bush, H. M., Thomas, S. M., Foss, K. D., Myer, G. D., & Hewett, T. E. (2017). Preventive neuromuscular training for youngfFemale athletes: Comparison of coach and athlete compliance rates. *Journal of Athletic Training, 52*(1), 58-64. doi:10.4085/1062-6050-51.12.20

Sugimoto, D., Myer, G. D., Foss, K. D., & Hewett, T. E. (2014). Dosage effects of neuromuscular training intervention to reduce anterior cruciate ligament injuries in female athletes: meta- and sub-group analyses. *Sports Medicine, 44*(4), 551-562. doi:10.1007/s40279-013-0135-9

Sutherland, K., Clatworthy, M., Fulcher, M. L., Chang, K., & Young, S. W. (2019). Marked increase in the incidence of anterior cruciate ligament reconstructions in young females in New Zealand. *Australiand and New Zealand Journal of Surgery, 89*(9), 1151-1155. doi:10.1111/ans.15404

Swart, E., Redler, L., Fabricant, P. D., Mandelbaum, B. R., Ahmad, C. S., & Wang, Y. C. (2014). Prevention and screening programs for anterior cruciate ligament injuries in young athletes: a cost-effectiveness analysis. *Journal of Bone and Joint Surgery in America, 96*(9), 705-711. doi:10.2106/jbjs.M.00560

Tabben, M., Whiteley, R., Wik, E., Bahr, R., & Chamari, K. (2019). Methods may matter in injury surveillance: "how" may be more important than "what, when or why". *Biology of Sport, 37*(1), 3-5. doi:10.5114/biolsport.2020.89935

Talpey, S. (2015). Competitive load of high performing junior basketball players during a national tournament. *Journal of Science and Medicine in Sport, 19*, 93. doi:10.1016/j.jsams.2015.12.356

Thomas, C., Comfort, P., Jones, P. A., & Dos'Santos, T. (2017a). A comparison of isometric midthigh-pull strength, vertical jump, sprint speed, and change-of-direction speed in academy netball players. *International Journal of Sports Physiology and Performance, 12*(7), 916-921. doi:10.1123/ijspp.2016-0317

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

Tiggelen, D., Wickes, S., Stevens, V., & Roosen, P. (2008). Effective prevention of sports injuries: A model integrating efficacy, efficiency, compliance and risk-taking behaviour. *British journal of sports medicine, 42*, 648-52. 10.1136/bjsm.2008.046441.

Tsoukas, D., Fotopoulos, V., Basdekis, G., & Makridis, K. G. (2016). No difference in osteoarthritis after surgical and non-surgical treatment of ACL-injured knees after 10 years. *Knee Surgery and Sports Traumatology, Arthroscopy, 24*(9), 2953-2959. doi:10.1007/s00167-015-3593-9

van Mechelen, W. (1997). Sports injury surveillance systems: 'One size fits all?'. *Sports Medicine, 24*(3), 164-168.

van Mechelen, W., Hlobil, H., & Kemper, H. C. (1992). Incidence, severity, aetiology and prevention of sports injuries. A review of concepts. *Sports Medicine, 14*(2), 82-99. doi:10.2165/00007256-199214020-00002

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

Vleeming, A., Pool-Goudzwaard, A. L., Stoeckart, R., van Wingerden, J. P., & Snijders, C. J. (1995). The posterior layer of the thoracolumbar fascia. Its function in load transfer from spine to legs. *Spine, 20*(7), 753-758.

Waldén, M., Atroshi, I., Magnusson, H., Wagner, P., & Hägglund, M. (2012). Prevention of acute knee injuries in adolescent female football players: cluster randomised controlled trial. *British Medical Journal, 344*, 3042. doi:10.1136/bmj.e3042

Waldén, M., Hägglund, M., Krosshaug, T., Bjørneboe, J., Andersen, T. E., & Faul, O. (2015). Three distinct mechanisms predominate in noncontact anterior cruciate ligament injuries in male professional football players: A systematic video analysis of 39 cases. *British Journal of Sports Medicine, 49*(22), 1452-1460. doi:10.1136/bjsports-2014-094573

Weiss, K., & Whatman, C. (2015). Biomechanics associated with patellofemoral pain and acl injuries in sports. *Sports Medicine, 45*(9), 1325-1337. doi:10.1007/s40279-015-0353-4

Whatman C., & Reid, D (2017). Movement quality, physical performance and prevalence of overuse injuries in secondary school netball players. *New Zealand Journal of Sports Med*; 44(1): 14-19.

White, P. E., Otago, L., Saunders, N., Romiti, M., Donaldson, A., Ullah, S., & Finch, C. F. (2014). Ensuring implementation success: how should coach injury prevention education be improved if we want coaches to deliver safety programmes during training sessions? *British Journal of Sports Medicine, 48*(5), 402-403. doi:10.1136/bjsports-2012-091987

White, P. E., Ullah, S., Donaldson, A., Otago, L., Saunders, N., Romiti, M., & Finch, C. F. (2012). Encouraging junior community netball players to learn correct safe landing technique. *Journal of Sciene and Medicine in Sport, 15*(1), 19-24. doi:10.1016/j.jsams.2011.08.004

Williams, R., & O'Donoghue, P. G. (2005). Lower limb injury risk in netball: A time-motion analysis investigation. *Journal of Human Movement Studies, 49*, 315-331.

Wright, I. C., Neptune, R. R., van den Bogert, A. J., & Nigg, B. M. (2000). The influence of foot positioning on ankle sprains. *Journal of Biomechanics, 33*(5), 513-519. doi:10.1016/s0021-9290(99)00218-3

Wright, M. D., Portas, M. D., Evans, V. J., & Weston, M. (2015). The effectiveness of 4 weeks of fundamental movement training on functional movement screen and physiological performance in physically active children. *J Strength Cond Res, 29*(1), 254-261. doi:10.1519/jsc.0000000000000602

Yom, J. P., Simpson, K. J., Arnett, S. W., & Brown, C. N. (2014). The effects of a lateral in-flight perturbation on lower extremity biomechanics during drop landings. *Journal of Applied Biomechanics, 30*(5), 655-662.

Yoo, J. H., Lim, B. O., Ha, M., Lee, S. W., Oh, S. J., Lee, Y. S., & Kim, J. G. (2010). A meta-analysis of the effect of neuromuscular training on the prevention of the anterior cruciate ligament injury in female athletes. *Knee Surgery and Sports Traumatology, Arthroscopy, 18*(6), 824-830. doi:10.1007/s00167-009-0901-2

Zarei, M., Abbasi, H., Daneshjoo, A., Barghi, T. S., Rommers, N., Faude, O., & Rössler, R. (2018). Long-term effects of the 11+ warm-up injury prevention programme on physical performance in adolescent male football players: a cluster-randomised controlled trial. *Journal of Sports Sciences, 36*(21), 2447-2454. doi:10.1080/02640414.2018.1462001

Zazulak, B. T., Hewett, T. E., Reeves, N. P., Goldberg, B., & Cholewicki, J. (2007). Deficits in neuromuscular control of the trunk predict knee injury risk: A prospective biomechanical-epidemiologic study. *American Journal of Sports Medicine, 35*(7), 1123-1130.

APPENDIX I- Original NetballSmart Warm-up Wallet

APPENDIX II: NetballSmart Dynamic Warm-up

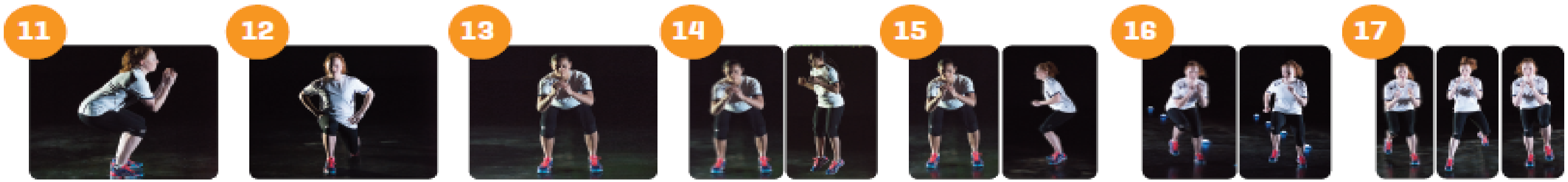
NETBALLSMART DYNAMIC WARM UP

NETBALL NEW ZEALAND   ACC SportSmart   NetballSmart

	NetballSmart Dynamic Warm-up	Time/Distance/Reps
Part A: Strengthening	1. **The Bench** i. The Bench - Static. Static bench on forearms (or hands) and feet. Lift pelvis off the ground. ii. The Bench - alternate leg (hold each 2 seconds). Continue for 20 – 30 seconds iii. Bench on forearms (or hands) and feet. Lift one leg and hold for 20-30 seconds	3 x 20-30 sec 3 x 20 – 30 sec 3 x 20 – 30 sec hold, alternative sides
	2. **Hips – Sideways Bench** i. Sideways bench – static. On elbow (or hand) and knee on ground or leg straight. Top leg out straight. Lift pelvis and maintain position. ii. Sideways bench raise and lower hips. On elbow (or hand) and legs out straight, raise and lower hips. iii. Sideways bench with leg lift. On elbow (or hand) and legs out straight. Lift hips, lift top leg and lower. Continue for 20 - 30 seconds.	2-3 x 30s ea side 2-3 x 30s ea side 2-3 x 30s ea side
	3. **Hamstrings** i. Beginner Nordic hamstring or Single leg Romanian Dead Lift (RDL) ii. Intermediate Nordic hamstrings or Single leg Romanian Dead Lift (RDL) iii. Advanced hamstring Single leg Romanian Dead Lift (RDL) throw and catch ball	3-5 or 3-5 each leg 7-10 or 5 each leg 10 each leg
	4. **Balance** i. Single leg stance – hold the ball (or imaging holding ball). Progress to moving ball around back. ii. Single leg standing throwing ball with partner iii. Single leg stance – test your partner. Facing partner. Hand on opposite shoulder of partner, tap each other. Keep balanced if possible or return to starting position. Continue for 30 seconds.	2 x 30 sec ea side 2 x 30 sec ea side 2 x 30 sec ea side
Part B: Running Warm-up Place 2 cones out every 3 metres between base line and centre court	5. **Running Straight Ahead.** Run to centre of court and back. Repeat. You can vary direction of the running path as it happens in a Netball game.	2 x 15 metres
	6. **Running Hip Out.** Run to first cone, stop, lift knee forwards and rotate knee out to side and put foot down. Run to next cone and repeat with other leg.	2 x 15 metres
	7. **Butt Kicks and skipping.** Butt kick to first cone (kicking feet up to butt), skip to next cone, butt kick to third cone. Continue for length of 15m and back.	2 x 15 metres
	8. **Running – Circling Partner.** Run to first cone, side shuffle inwards towards and around partner and back out to cone. Run to next cone and repeat. Continue length of 15m and back.	2 x 15 metres
	9. **Running – Shoulder Contact.** Run to cone, side shuffle to the middle, jump shoulder to shoulder contact. Land in good stable body positon. Continue length of 15m and back.	2 x 15 metres
	10. **Running - Quick Forwards and Backwards Sprints.** Run to second cone and back to first cone. Repeat 2 cones forwards one back for length of 15m and back.	2 x 15 metres

APPENDIX II: NetballSmart Dynamic Warm-up

Part C: Dynamic Preparation	11. **Squats** i. Squats ii. Squat, calf raise and body extension iii. Single leg squat iv. Combination of all three	10 10 10
	12. **Walking Lunges** i. Walking lunges ii. Walking lunges and calf raise iii. Walking lunges, calf raise and body extension	5 each side 5 each side 5 each side
	13. **Jumping and landing** i. Vertical jump and land on 2 feet in a stable body position (SBP) ii. Lateral jump– jump sideways 1m off one leg and land on other leg. iii. Broad jump – jump forward 1m off two and land on one foot hold one sec in a stable body position on one foot	5 each side 5 each side 5 each side
	14. **Jumping, turning and landing** i. Vertical jump and turn 90 degrees and land in SBP ii. Vertical jump and turn 180 degrees and land in SBP iii. Vertical jump and turn 270 degree and land in SBP	5 turns each side 5 turns each side 5 turns each side
Part D: Netball Specific Preparation	15. **Running and Stopping.** Run to first cone at 75- 80% speed and stop. Use either a double foot or 1-2 foot landing. Continue length of 15 metre and back stopping at each cone.	2 x 15m
	16. **Running - Plant and Cut.** Run at 80-90%. Run to first cone, plant, and cut off on an angle towards opposite cone. Continue length of 15 metre and back	2 x 15m
	17. **Prop, Prop & Stick.** Prop from one foot to another and then "stick" final landing for 2 seconds in a stable body position.	15m and jog back



APPENDIX III: NetballSmart Power Warm-up

NETBALLSMART POWER WARM-UP

NETBALL NEW ZEALAND ACC SportSmart NetballSmart

This shortened warm-up is ideal for the tournament setting where time is limited and a full warm-up is not necessary for every game.

	NetballSmart Power Warm-Up	Time/Distance/Reps
Part B: Running Warm-Up Place 2 cones out every 3 metres between base line and centre court.	5. **Running Straight Ahead.** Run to centre of court and back. Repeat. You can vary direction of the running path as it happens in a Netball game.	2 x 15 metres
	8. **Running – Circling Partner and Shoulder Contact.** Run to first cone, side shuffle inwards and around partner and back out to cone. Run to next cone, side shuffle to the middle, jump and shoulder contact. Land in good stable position. Continue length of 15m and back.	2 x 15 metres
	10. **Running - Quick Forwards and Backwards Sprints.** Run to second cone and back to first cone. Repeat 2 cones forwards one back for length of 15m and back.	2 x 15 metres
Part C: Dynamic Preparation	11. **Squats** i. Squats, calf raise and body extension ii. Single leg squats each leg	 5 each side 3 each side
	12. **Walking Lunges.** Walking lunges, calf raise and body extension	5 each side
	13. **Lateral jump.** Jump sideways 1m off one leg and land on other leg. Land in SBP on 1 leg. Hold for 1 second.	3 each side
Part D: Netball Specific Preparation	15. **Running, Stopping and Jump, Turn and Land.** Run to first cone at 75-80% speed and stop double foot landing and jump 180 degrees, land in SBP and return. Run to next cone and do 1-2 foot landing. Jump 90 degrees and land in SBP and return. Continue length of 15 metres and back.	2 x 15 metres
	17. **Prop, Prop and Stick.** Prop from one foot to another and then "stick" final landing for 2 seconds in a stable body position.	15 metres and jog back

Numbering is consistent with the full NetballSmart Dynamic Warm-Up which can be found under *Resources* when you visit **netballnz.co.nz/useful-info/netball-smart**

APPENDIX IV: Conference Abstract 2018

TEN YEAR REVIEW OF LOWER EXTREMITY NETBALL INJURIES IN NEW ZEALAND

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Aim: To review epidemiological data collected for netball lower extremity injuries by the Accident Compensation Corporation (ACC) between 2008 and 2017.

Methods: Data was sourced by the ACC, covering the key search criteria: Count of new netball related claims by body site, cost and age groups. The data was divided into 5 equal year groups (2008/9, 2010/11, 2012/13, 2014/15, 2016/17), and 3 age groups (Group 1= 10 to 14 years, Group 2= 15 to 19 years and Group 3= 20 to 24 years old). These age groups were chosen as they ranked the highest for ankle, knee and lower extremity injuries over the 10-years. Injury incidence and rate of cost was calculated as number of netball injuries per 1000 affiliated membership population. All costs given by ACC were corrected for the effect of inflation using consumer price index (CPI) rates for each year. Affiliated member numbers were sourced by Netball New Zealand (NNZ) and the number of affiliates for each age group calculated to mirror the age brackets displayed in the ACC data. All comparisons between age groups were performed using a Cuzick test (adapted Wilcoxon test for trend) and a Poisson regression test to compare across years for each age group.

Results: In 2017 of all netball injury claims against ACC, 61% were to the lower extremity, costing NZD$20,051,919. Ankle and knee injuries constitute 47% of all injury claims a year, but more significantly in 2017, 66% of the cost to the public at NZD$18,049,370. The youngest age group (10-14 years old) showed the highest percentage increase in injury rate between 2008 and 2017 for both ankle (98% increase) and knee injuries (150% increase), compared to Group 2 ankle (51% increase) and knee injuries (60% increase) and Group 3 ankle (15% decrease) and knee injuries (23% increase). However, the reverse is seen for rate of cost per 1000 members between 2008 and 2017, Group 3 had the highest increase in rate (73%), compared to Group 2 (50%) and Group 1 (42%). There was a statistically significant difference between age groups (p=0.001) in the average injury rate across the 10-year period. The older age group (20-24 years) had the highest injury rate (ankle=77.8, knee=71.6 injuries/1000 players) compared to Group 2 (ankle=71.6, knee=34.8 injuries/1000 members) and Group 1

(ankle=38.2, knee=19.4 injuries/1000 members). Finally, there was a significant difference between groups in the average cost of all lower extremity injuries (p = 0.005), Group 1 (cost = $21,880/1000 members), Group 2 (cost = $93,731/1000 members) and Group 3 (cost = $182,406/1000 members). There was a noticeable trend pattern for increasing ankle injuries in group 1 and 2 (p = 0.072) and knee injuries in group 1 (p = 0.072), but no trend pattern was significant.

Conclusion: These results suggest that for the ACC and NNZ the focus of injury prevention should continue to be directed at prevention of lower extremity injuries. Particular focus should be on younger players (10-14 years) as they have had the highest percentage increase in lower extremity injuries from 2008-2017. Additionally, as they have the highest current injury rate and cost, older players (20-24 years) should also be a key target group. The limitations of ACC database injury definitions and the exposure data used in this study need to be acknowledged.

APPENDIX V: Conference Abstract 2020

NETBALL NEUROMUSCULAR WARM-UP IMPROVES LANDING TECHNIQUE

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Introduction: Netball is a popular female sport in secondary schools with a high incidence of injury, especially to the lower extremity. One of the major contributors to injury is thought to be poor landing technique. Netball NZ partnered with Accident Compensation Corporation (ACC) to create an injury prevention warm-up called the NetballSmart Dynamic Warm-up (NSDW). Subsequently an additional Power Warm-up (PWU) was development in response to coach feedback the NSDW was not appropriate for all situations.

Objective: To investigate the efficacy of two 'NetballSmart', netball specific warm-ups in improving landing technique measures in New Zealand secondary school netball players.

Design: Multi-site cluster experimental trial.

Setting: Secondary school netball, 12 teams from 6 schools performed either the NSDW or the PWU three times a week for 12 weeks.

Participants: 77 youth netball players, mean ±SD age = 15.8 ± 0.9; NSDW group (n = 37); PWU group (n = 40).

Main Outcome Measures: All participants completed a drop vertical jump on a portable force plate. Measures included peak ground reaction force (GRF) for double leg (DL) and single leg (SL) landings; frontal plane projection angle (FPPA) for right and left single leg landings; Landing error scoring system (LESS), a count of landing "errors" (higher score indicates poorer landing). Paired t-tests were used to assess mean differences pre and post the intervention.

Results: Significant improvements were found in all the landing technique outcome measures for both warm-up groups (Table 1).

Conclusion: The results of this study show that both the NSDW and PWU can improve landing technique measures in youth secondary school netball players. It is recommended that coaches should consider implementing one of the two warm-ups in their netball programmes. Their choice of warm-up will likely be dependent on the environment they are performing in and time demands.

Table 1: Changes in landing technique

	Pre-Test Mean ± SD	Post Test Mean ± SD	Difference in Mean (95% CI)	Effect Size (95% CI)	P Value
NSDW					
GRF DL (n)	3233.9 ± 930.1	2591.0 ± 583.8	-642.4 (-342.7 to -942.1)	0.8 (0.3 to 1.3)	0.001*
GRF R SL (n)	2861.7 ± 745.8	2482.2 ± 550.7	-379.5 (-141.7 to -617.2)	0.6 (0.1 to 1.0)	0.003*
GRF L SL (n)	2768.1 ± 728.0	2182.7 ± 736.8	-585.4 (-300.8 to -890.0)	0.8 (0.3 to 1.3)	0.001*
FPPA R (°)	-13.8 ± 6.7	-7.7 ± 8.3	6.1 (3.3 to 8.8)	0.8 (0.3 to 1.27)	0.001*
FPPA L (°)	-13.6 ± 5.8	-5.1 ± 8.4	8.5 (6.4 to 8.4)	1.2 (0.7 to 1.7)	0.001*
LESS	7.9 ± 2.1	4.9 ± 1.6	3.0 (2.3 to 3.6)	1.6 (1.1 to 2.1)	0.001*
PWU					
GRF DL (n)	3451.9 ± 963.0	2565.8 ± 609.8	-886.1 (-539.4 to -1232.7)	1.1 (0.6 to 1.6)	0.001*
GRF R SL (n)	3148.1 ± 742.7	2571.2 ± 527.1	-576.9 (-315.0 to -838.8)	0.9 (0.4 to 1.4)	0.001*
GRF L SL (n)	3250.5 ± 712.7	2515.5 ± 585.5	-734.9 (-492.4 to -977.5)	1.1 (0.6 to 1.6)	0.001*
FPPA R (°)	-14.0 ± 7.3	-5.9 ± 6.0	8.1 (5.7 to 10.4)	1.2 (0.7 to 1.7)	0.001*
FPPA L (°)	-14.9 ± 7.8	-5.7 ± 8.0	9.1 (6.6 to 11.7)	1.2 (0.7 to 1.6)	0.001*
LESS	9.17 ± 1.91	3.86 ± 1.31	5.31 (4.71 to 5.91)	3.2 (2.5 to 3.9)	0.001*

NSDW= NetballSmart dynamic warm-up, PWU= Power warm-up, GRF= ground reaction force, FPPA= frontal plane projection angle, DL=double leg, SL=single leg; n= newtons* significantly different ($P < 0.05$).