An Evaluation of the NetballSmart Dynamic Warm-up in Youth Netball

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Abstract

Netball is a popular, physically demanding female sport with a high risk of lower limb injury, particularly to the ankle and knee. Neuromuscular warm-up programmes can enhance modifiable factors that have been linked to performance and injury risk in both adult and youth team-sport athletes. The current evidence for this however is largely limited to male football. Additionally, as coaches are key to the successful implementation of these programmes, their feedback and further evidence of the performance benefits is needed. The overall purpose of this thesis was to determine if the recently developed NetballSmart Dynamic Warm-up can improve physical performance measures in female youth netball players. Additionally, there was a focus on exploring the role of the coach in the implementation of the warm-up.

To better understand the training needs of a female youth netball player, a physical performance profile of this group was determined. Differences were found in anthropometry, horizontal and vertical jump performance, balance, core strength, change of direction speed and sprint times between grades and playing positions (*n*= 102; ES= 0.28 to 1.37). Results showed that players in higher grades performed physically better than lower grades. A physical performance profile could be used for talent identification and for guiding training programmes. Once a physical performance profile had been established, the same physical performance measures were used to investigate the effect of the NetballSmart Dynamic Warm-up on performance. Significant improvements in prone hold (β= 20.46 s; p= 0.01) and vertical jump (β= 6.73 cm; p= 0.01) were found in the intervention group (*n*= 45) compared to the control group (*n*= 36). In a sub-group study, the warm-up did not improve isokinetic knee flexor or extensor strength (60 º/s; p= 0.08-0.90) or change the hamstring to quadriceps ratio (mean difference= -0.02; p= 0.25). Both these studies provided preliminary evidence that some physical performance measures can be improved with this neuromuscular warm-up which will be useful when promoting the programme to coaches. Given the key role of the coach when including a new warm-up in training, coach experience of the warm-up and their knowledge and attitude to injury was evaluated through a coach survey.

The initial feedback on the warm-up provided by coaches was encouraging. Poor technique was perceived to be the most common injury risk factor (87%) in netball and the ankle was correctly reported as the most common lower limb injury (67%). The majority of coaches (93%) felt their personal coaching experience was sufficient to be able to coach the warm-up but reported barriers to the translation of the programme into the netball environment may cause delays in programme implementation and uptake. As coaches are a key influence in the adoption and maintenance of injury prevention

programmes, these barriers need to be addressed to ensure the sustainability and success of the warm-up programme.

Physical performance in youth netballers differs by playing grade and position and some performance factors can be improved with the implementation of the NetballSmart Dynamic Warm-up. It is recommended the warm-up be implemented in regular youth netball training guided by current and future coach feedback.

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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.

Chapters 3 to 6 of this thesis represent separate papers that have either been published or submitted to peer-reviewed journals. All co-authors have approved the inclusion of the joint work in this doctoral thesis.

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Chloe Renee McKenzie

21st April 2019

Co-Authored Works

Table 1. Co-authored works.

Chapter publication reference		**Author %**
Chapter 2.	McKenzie, C.R., Whatman, C., Brughelli, M. (2019). The effect of neuromuscular warm-up programmes on physical performance measures: A narrative review.	CM: 90% CW: 5% MB: 5%
Chapter 3.	McKenzie, C.R., Whatman, C., Brughelli, M. (2019). Performance profiling of female youth netball players. *Journal of Strength and Conditioning Research*: [E-pub Ahead of Print].	CM: 90% CW: 5% MB: 5%
Chapter 4.	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.	CM: 85% CW: 5% MB: 5% RB: 5%
Chapter 5.	McKenzie, C.R., Brown, S.R., Whatman, C., Brughelli, M. (2019). The effect of the NetballSmart Dynamic Warm-up on isokinetic knee strength in youth netball players*. New Zealand Journal of Sports Medicine*: [in review].	CM: 85% CW: 2.5% MB: 2.5% SB: 10%
Chapter 6.	McKenzie, C.R., Whatman, C., Walters, S., Brughelli, M. (2019). Implementation of the NetballSmart Dynamic Warm-up: The role of the coach. *International Sport Coaching Journal*: [submitted].	CM: 85% CW: 7.5% MB: 2.5% SW: 5%

We, the undersigned, hereby agree to the percentages of participation to the chapters identified above:

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To my family and friends, near and far- I am so grateful to have many wonderful people in my life. Thank you for your love, unconditional support and kind words, as well as providing a happy distraction to rest my mind outside of my research when I needed it. Mum, thank you for always being there- my number one supporter.

My life has been forever changed as a result of completing this PhD, thank you all again.

Ethics Approval

Ethical approval for this thesis research was granted by the Auckland University of Technology Ethics Committee (AUTEC) on 18th January 2016 for a period of three years:

- AUTEC: 15/458- Effects of a modified Fifa 11+ warm-up programme on physical performance in youth netballers.

Subsequent amendments approved by AUTEC:

- Data collection procedures- 7th April 2016
- Participant inclusion criteria- 14th July 2016
- Participant recruitment protocols and thesis title change- 10th April 2017

Chapter 1: Introduction and Rationale

The sport of netball

Based on an early version of basketball, the sport of netball was officially developed in England in 1901 (145). At that time, it was considered an acceptable sport for women to play as the physical restraint of the game appeared to conform to the then idea of femininity, despite it requiring vigorous activity (145). Netball is still considered a non-contact sport today, however the physicality and demands of the game have increased over time. Netball is played in a number of countries around the world, but due to its origins it is largely confined to the commonwealth countries (145). Following introduction to New Zealand (NZ) in 1906 (94), netball has grown to be the country's most popular women's sport with a reported 144,358 affiliated players in 2017 (92). It is also the number one sport played by girls in secondary schools (92).

To provide some context of the game, netball is an intermittent team sport played on a 30.5 x 15.25 m court which is divided into thirds (10.17 m long) (139). There is a "centre circle" in the middle third from which play begins (Figure 1). Two teams of seven players are on court at a time. Each player has a certain position restricting them to certain areas of the court. Positions are separated into centre court (centre [C], wing attack [WA], wing defence [WD]), shooters (goal shoot [GS], goal attack [GA]) and defenders (goal keep [GK], goal defence [GD]) (139). Each team has a goal post at either end of the court and shooters must score as many goals as possible within a 60-minute match (15-minute quarters) to win the game (one point is awarded per goal scored) (96).

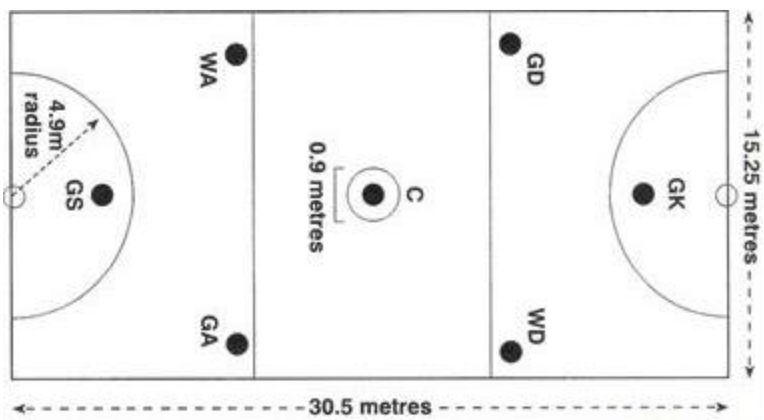

Figure 1. Outline of a netball court with 7 players in starting positions

As netball is a dynamic and physically demanding game, it requires a high level of fitness, strength, speed and agility (84, 134). It involves acceleration and deceleration, cutting and changes of direction, jumping/landing and lunging; all while catching, passing and shooting a ball (44). A unique rule that distinguishes the sport of netball from its origin (basketball) is the footwork rule. When a player lands with the ball in their hands, the first foot they land on is termed the “grounded foot” and this foot must stay on the ground or in the air until the player has released the ball. Re-grounding the grounded foot while still in possession of the ball is a “step”, which results in a turn-over of ball to the opposition. Equally, a hop, slide or drag of the grounded foot is classified as “stepping” and penalised infringing the footwork rule (95).

Injuries in netball

When receiving a pass at speed, a netball player must rapidly reduce horizontal velocity to come to a sudden stop to avoid violating the footwork rule. These abrupt decelerations impose high ground reaction forces (GRFs) on the lower body (139). Incorrect technique and insufficient neuromuscular control during deceleration and landing increases the risk of injury to the lower extremities (106). The most frequent cause of injury in netball is poor landing technique, collisions with players, being struck by the ball, or repetitive movement (i.e. jump/land, acceleration/deceleration, change of direction) (63). The locations of lower extremity injuries include the ankle (most common) (8, 106) and the knee (most expensive and often longest time out of the game) (84, 134, 139) with ligament sprains, bruising/contusions, and muscle strains reported as the most common injury types (63). The prevalence of injury during one season of netball in amateur and elite female netball players is estimated at between 54-57% (8, 106). More injuries occurred during match play than in training and the overall incidence of injury was 5.72 injuries / 1000 athlete hours in amateur netball players (106) and 9.08 injuries / 1000 athlete hours in elite netball players (8).

It has been well documented that female sports involving change of direction and jumping have a high incidence of knee injury (52). The most common knee injury in netball is an anterior cruciate ligament (ACL) rupture (139). An analysis into the mechanisms of 16 ACL injuries sustained in netball found that 13/16 occurred while landing from a jump; 6/16 occurred due to an unbalanced landing; 4/16 occurred during rapid breaking; and 12/16 occurred due to an apparent knee valgus collapse (135). The likelihood of sustaining an ACL injury in a non- contact sport such as netball is two to eight times greater for females than males (89). Higher peak knee valgus angles and lower peak hip and knee flexion in adult female basketball players (compared to males) during movements linked to non-contact ACL injury (sidestep, jump-land, shuttle run), may explain the increased risk (83). The increased susceptibility to ACL injury has also been found in the adolescent age-group (75, 111). The inability of female athletes to improve neuromuscular control after pubertal changes may add to the higher risk of ACL injury in the adolescent years following the onset of puberty (111). Therefore, the combination of greater knee valgus angles, decreased hip and knee flexion, and higher GRFs during landing and cutting movements may account for the high lower extremity injury risk in netball (139).

Physical performance measures and injury risk

Physical performance measures such as movement technique, balance/proprioception and strength are associated with injury risk (3, 87, 101, 108). For example, a lack of strength or a strength imbalance can increase the risk of knee injury (89). Weakness about the knee, particularly in the hamstring muscles, has been shown to increase ACL injury risk in female athletes (87). Furthermore, eccentric strength deficits are of particular concern in ACL injury prevention as injuries occur more frequently during deceleration movements (97). Increased internal tibial rotation, combined with greater quadriceps activity and a low hamstring to quadriceps (H:Q) ratio, could also explain the higher incidence of non-contact ACL injuries in females (89). Furthermore, strength imbalances between the quadriceps and hamstrings muscle groups have been linked to hamstring strain injuries (101). Thus, strength deficits may lead to netballers adopting poor lower extremity landing mechanics leading to increased injury risk in netball specific landing tasks. Single leg balance has also been identified as a risk factor for injuries (3, 108). A shorter reach distance (≤ 77.5% of leg length) in the posterior-medial direction of the star excursion balance test increased the probability of sustaining an ankle sprain during netball (four times greater risk) (3). As physical performance measures have been shown to effect injury risk, tools that assess these performance measures could be used to help identify and reduce the risk of injury. As well as aiding injury prevention, physical performance data could also inform training for performance enhancement. With detailed information on physical performance characteristics it may be possible to identify factors, such as muscle weakness and poor movement mechanics, which contribute to injury risk and reduced performance. Efforts can then be focused on improving these modifiable physical characteristics (73).

Physical performance, injury risk and performance profiling in youth athletes

Adolescent youth play sport for many reasons, including psychosocial benefits of greater self-confidence, skill development, socialisation, teamwork and competition (26). However, the number of young people that continue playing sport at either a high level or recreational level into adulthood is relatively small (26, 74). Sport injury may contribute to the reduction in sport participation with 8% of youth reportedly dropping out of sport annually because of injury (26). Sport is the leading cause of injury in youth, accounting for more than 30% of all youth injuries in some estimates (26). Therefore, due to high participation rates and high injury rates in this age group, it is important to ensure that youth athletes are provided with opportunities to enhance their physical development and reduce the risk of sport-related injury (43, 74). With this in mind it has been suggested that improving muscular strength should be a priority at all stages of youth development for males and females (73). Close associations have been found between muscular strength and running speed, muscular power, change of direction speed, jump ability and endurance (73). Additionally, as in adults, strength is an important factor for correct technique across a range of movements (73). Furthermore, mobility and stability have also been described as underpinning qualities in a player's ability to perform fundamental movements (43). Thus, including muscular strength development and neuromuscular training in strength and conditioning programmes is not only crucial for enhancing sport performance, but also for reducing sport-related injury risk (43, 73). To enhance performance and reduce the risk of injury it is crucial that young netballers are equipped with adequate physical capabilities. There is some evidence in the published literature as to the physical demands and capabilities of netballers, specifically in youth (15, 126, 141, 142); however, further research is needed.

Research providing a physical performance profile, including anthropometric measures, of youth netball players could assist with physical development and performance enhancement. Physical performance profiling has been investigated in other sports (rugby league, football, Australian rules football, volleyball) (38, 40, 41, 47, 78) highlighting the knowledge of sport and position specific requirements can be useful for coaches to assist with training programs, ensuring athletes are physically prepared to perform successfully in a game (6, 142). In addition, performance profiles guiding physical development could also be used to aid talent identification (40). Several studies have reported physical activity profiles of adult netball players (6, 17, 22, 35, 36, 137), however there is limited observations of game demands in youth netball. There is currently no information on performance profiles of youth netball players in NZ, thus further research is needed to improve our understanding and assist netball and strength and conditioning coaches.

Neuromuscular warm-up programmes

Due to the high incidence of injury in netball, a broader promotion of injury prevention resources, combined with research into the effectiveness of these resources and how players can be encouraged to adopt appropriate injury prevention strategies, has been recommended (63). Injury prevention and performance enhancing programmes have been implemented, and shown to be effective, in netball and other sports (24, 25, 48, 61, 67, 124). These programmes include neuromuscular training programmes (24, 61), sport-specific neuromuscular warm-up programmes (124), and sport-specific balance programmes (25).

A particular injury prevention programme that has reported success in reducing injuries is the FIFA 11+ (50, 76, 104, 124, 128). The FIFA 11+ is a structured, exercise-based neuromuscular warm-up programme designed to reduce injuries among female and male football players aged 14 years and older (104, 124). The warm-up has been shown to significantly reduce injury rates by 46% and decrease time-loss to injury by 29% when performed three times per week across a season of football (124). Furthermore, the FIFA 11+ warm-up can enhance physical performance (10). The warm-up has been shown to induce improvements in balance and stability, sprint, agility and vertical jump performance in football (4, 10, 65). This could, in part, explain possible underlying mechanisms of neuromuscular warm-up programmes linked to both performance and injury risk. The FIFA 11+ was developed by a group of international experts from FIFA's Medical Assessment and Research Centre (F-MARC), the Oslo Sports Trauma Research Centre and the Santa Monica Orthopedic and Sports Medicine Research Foundation (9). The structure and specific exercises included in the FIFA 11+ make it different to other previously implemented neuromuscular warm-up programmes. It has three parts that are performed in order (28). Part 1 involves running exercises at a slower pace, combined with active stretches and some partner contact in a controlled manner. Part 2 focuses on strength of the core and lower body, balance, plyometrics and agility. This section is made up of six different exercises, each with three levels of increasing difficulty. Part 3 involves running exercises at moderate to high speeds, combined with cutting movements. Exercises included in the programme are suggested to be "evidence-based" and/or "best practice" designed to prevent the most frequent types of injury in football (28). The developers of the programme identified core strength, neuromuscular control and balance, eccentric training of the hamstrings, plyometrics and agility training as important components of effective injury prevention; therefore, exercises such as prone holds, Nordic hamstring drops, and vertical jumps have been included in the warm-up programme (28). In addition to warming the body in preparation for training or games, adding these components and exercises into a warm-up should lead to improvements in core and lower body muscle strength, static, dynamic and reactive neuromuscular control, agility and jump techniques (28). A key element of the programme is using correct technique and proper movement, particularly correct posture and body control and alignment (28). For more details on the FIFA 11+, see the freely available instructions and manual on the official website (www.f-marc.com/11plus).

In 2016, largely due to the success of the FIFA 11+ programme, Netball NZ (NNZ) designed the NetballSmart Dynamic Warm-up based on the structure and exercises performed in the FIFA 11+ (See Appendix B for a summary of the NetballSmart Dynamic Warm-up). Slight modifications were made to the programme to make it more sport-specific to netball (93). NetballSmart is a collaboration between NNZ and the Accident Compensation Corporation (ACC) which is focused on decreasing the frequency and cost of injuries in netball players in NZ. In an effort to reduce injuries, the injury prevention warm-up was introduced as a part of the NetballSmart programme and NNZ has been promoting the warm-up across all of youth netball. Although similar warm-ups such as the FIFA 11+ have been shown to be successful in football there is no evidence of their effect in netball.

Evidence has suggested that neuromuscular injury prevention warm-up programmes have been successful in reducing injury risk and improving performance during controlled trials, however achieving adequate compliance to such programmes can be challenging (98). The most common Sports Injury Prevention model was originally introduced by van Mechelen and colleagues (1992) and more recently developed by Finch (2006) as the Translating Research into Injury Prevention Practice (TRIPP) framework (Table 2). The main limitation to the Sports Injury Prevention model addressed by the TRIPP model is the consideration for research leading to real-world sports injury prevention environments (31). The original model could provide evidence of effective prevention measures (147), however it did not ensure uptake or implementation of interventions (31). The addition of stages 5 and 6 of the TRIPP framework are of particular importance for injury prevention. These stages help to understand the barriers and facilitators to the implementation and sustainability of the programme (33). Since the development of the TRIPP framework, the Reach Efficacy Adoption Implementation Maintenance (RE-AIM) framework and the RE-AIM Sports Setting Matrix have also been introduced to attempt to identify the specific implementation components that influence the adoption, execution and maintenance of interventions (26, 33, 98).

A common factor in the successful implementation of an injury prevention programme in both frameworks is the role of the coach (123, 151). Compliance has been shown to influence efficacy of the FIFA 11+ programme, thus it is crucial that coaches are able to motivate their players to learn the programme and perform the exercises correctly and regularly (129). Coaches are responsible for encouraging and ensuring their players adopt and follow safe training practices (151). To ensure effective implementation of new injury prevention programmes adequate coach involvement, knowledge and education is vital (129, 151). Thus, evaluating the coach experience when implementing any new programme is crucial. Additionally, performance enhancing benefits have been identified by coaches as a motivating factor to adopt and regularly deliver an injury prevention programme (123, 132). Thus, evidence the NetballSmart Dynamic Warm-up improves performance may increase coach uptake of the programme and consequently player adherence. Additionally, given the key role of the coach, their feedback and evaluation during the implementation of any new programme is crucial.

Table 2. Sports Injury Prevention frameworks.

Stage	Sports Injury Prevention model (147)	Translating Research into Injury Prevention Practice (TRIPP) (31)
1	Establish the extent of the problem	Injury Surveillance
2	Establish aetiology and mechanisms of injury	Establish aetiology and mechanisms of injury
3	Introduce preventative measures	Develop preventative measures
4	Assess their effectiveness by repeating Stage 1	“Ideal conditions”/scientific evaluation
5		Describe intervention context to inform implementation strategies
6		Evaluate effectiveness of preventative measures in implementation context.

Purpose of the thesis

The overall purpose of this thesis was to determine if the NetballSmart Dynamic Warm-up can improve physical performance measures in youth netball players.

Significance of the research

A better understanding of physical performance in youth netball and the potential benefits of neuromuscular warm-up will be valuable to coaches and players. As the physical condition of youth athletes has been linked to both performance and injury risk, a physical performance profile in youth netball players needs to be established. By determining a physical performance profile, modifiable factors that have been linked to both performance and injury risk (strength, balance, acceleration, deceleration and movement competency) can be evaluated in this group. Establishing this profile will help netball and strength and conditioning coaches understand factors that are most likely to influence performance and injury risk. Although the FIFA 11+ has been shown to improve physical performance and reduce injury risk, the efficacy of a neuromuscular warm-up is yet to be investigated in netball. By evaluating the effectiveness of the NetballSmart Dynamic Warm-up, it can be determined if the programme can improve physical performance measures linked to game performance and injury risk in youth netball players. Evidence the warm-up can improve physical performance is likely to increase coach uptake of the programme and lead to greater player adherence. Furthermore, understanding coach knowledge and attitudes towards injury prevention, as well as experiences with the NetballSmart Dynamic Warm-up, may be beneficial for implementation strategies of the programme.

Structure of the thesis

Under the Auckland University of Technology's format 2, this thesis contains three sections and six chapters suitable for journal publication (Figure 2). The three sections progressively address the overall purpose of this thesis. The first section of the thesis (Chapter 2 and 3) is focused on a narrative review of literature evaluating the effect of neuromuscular warm-up programmes on physical performance measures in both adult and youth athletes and provides a physical performance profile of female youth netball players. The narrative review (Chapter 2) also highlights implications for implementation and compliance to injury prevention programmes and identifies the relevance and importance of evaluating the NetballSmart Dynamic Warm-up in female youth netball players. The physical performance profile of youth netball players in New Zealand (Chapter 3) investigates differences in physical performance capabilities between youth netball players competing in different grades and playing in different positions. The second section of the thesis (Chapters 4 and 5) investigates the effect of the NetballSmart Dynamic Warm-up programme on physical performance measures (Chapter 4) and isokinetic strength (Chapter 5) in female youth netball players after a seven-week intervention. The third section of the thesis (Chapter 6) investigates the experience of the coach in injury prevention programmes with a coach survey. Coach knowledge and attitudes towards injury prevention in netball and their experience and thoughts of the NetballSmart Dynamic Warm-up are evaluated.

The appendices contain supportive or technical material for the individual chapters and/or thesis as a whole. Table 3 provides a detailed summary of the purpose and rationale for each chapter, key findings, novel contributions and links between chapters.

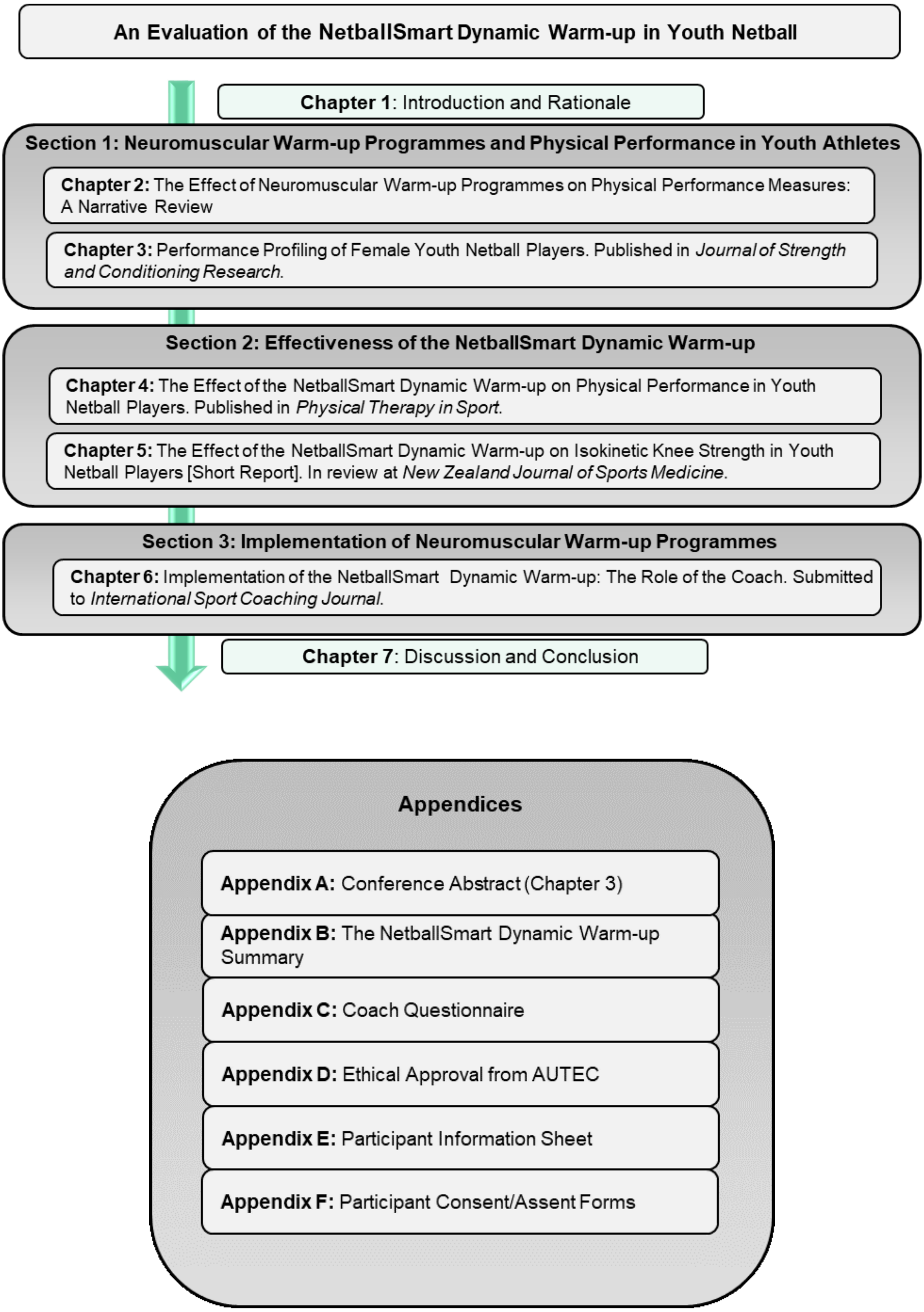

Figure 2. Overview of the thesis structure

Table 3. **Summary of thesis chapters.**

An Evaluation of the NetballSmart Dynamic Warm-up in Youth Netball		
Chapter	**Chapter Title**	**Chapter Summary**
1	**Introduction and Rationale**	**Purpose:** To provide background, rationale and significance to support the overall purpose of this thesis. An overview of the structure of the thesis is also presented.
Section 1		
2	**The Effect of Neuromuscular Warm-up Programmes on Physical Performance Measures: A Narrative Review**	**Purpose:** Examine the current evidence for the effect of neuromuscular warm-up programmes on measures of physical performance. **Rationale for the purpose:** Neuromuscular warm-up programmes, in particular the FIFA 11+, have been shown to reduce injury risk; however, there is little evidence as to the mechanisms for this. Therefore, it is important to understand how such programmes effect modifiable factors that have been linked to both performance and injury risk. **Approach:** Narrative review. **Findings:** • Neuromuscular warm-up programmes improve some physical performance measures in team-sport athletes. • Most of the research on this topic was conducted in male football players with little evidence in female athletes and other sports. • Research involving female or youth athletes was focused on biomechanical/ movement changes and there was little evidence for other performance measures (e.g. jump, speed, strength). **Novel Contribution:** We have provided a comprehensive critique and synthesis of the current evidence identifying the effect of neuromuscular warm-up programmes on physical performance measures.
	Prelude to Chapter 3: Having first identified gaps in the literature regarding the effect of neuromuscular warm-up programmes on physical performance measures, the next step was to assess the physical performance capabilities of female youth netball players. A physical performance profile for the measures identified in the literature and linked to the demands of netball would help to	

<table>
<tr><td></td><td colspan="2">understand how a neuromuscular warm-up programme could improve modifiable factors linked to performance and injury risk.</td></tr>
<tr><td>3</td><td>Performance Profiling of Female Youth Netball Players

Publication resulting from Chapter:
McKenzie, C.R., Whatman, C., Brughelli, M. (2019). Performance profiling of female youth netball players. Journal of Strength and Conditioning Research: [E-pub Ahead of Print].</td><td>Purpose:
Investigate the physical performance characteristics of New Zealand secondary school netball players to provide a physical performance profile. Secondly, to determine if there are differences between playing grades and playing positions.
Rationale for the purpose:
Identification of a physical performance profile can aid in understanding physical capabilities of players in relation to the demands of their specific sport. Little is known regarding physical characteristics of female youth netball players, playing positions and grades.
Approach:
Cross-sectional study.
Findings:
• Differences were found between playing grades. Higher grades demonstrated better physical ability than lower grades.
• Differences were found between playing positions of different grades.
• Differences were found between players with different anthropometric measures.
Novel Contribution:
This is the first study in youth netball to investigate physical performance and anthropometric differences between youth netball players of different playing grades and playing positions. It determined a profile for this age group and sport which could be useful to netball and strength and conditioning coaches for training and talent identification. Information can be used for position-specific training to help develop the capabilities needed for game-play. We recommend a programme incorporating speed, change of direction ability and plyometrics for non-circle positions and a focus on developing horizontal force production for circle positions.</td></tr>
<tr><td></td><td colspan="2">Prelude to Chapter 4 and 5:
A physical performance profile of youth netball players aged 13 to 14 years has been reported. This information can be used for physical development and talent identification. It is unknown if a neuromuscular warm-up, particularly the NetballSmart Dynamic Warm-up, can improve the identified performance measures.</td></tr>
<tr><td colspan="3">Section 2</td></tr>
</table>

4	**The Effect of the NetballSmart Dynamic Warm-up on Physical Performance in Youth Netball Players** **Publication resulting from Chapter:** 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.	**Purpose:** Investigate the efficacy of the NetballSmart Dynamic Warm-up in improving physical performance measures in New Zealand secondary school netball players. **Rationale for the purpose:** The NetballSmart Dynamic Warm-up aims to enhance performance and prevent injuries; however there has been no studies investigating the effect of this warm-up. Little is known on the effect of a neuromuscular warm-up on performance in female youth netball players. **Approach:** Cluster randomized controlled trial. **Findings:** • The NetballSmart Dynamic Warm-up improves prone hold and vertical jump performance. • The NetballSmart Dynamic Warm-up should be included in regular netball trainings. **Novel Contribution:** This was the first study to investigate the effect of the NetballSmart Dynamic Warm-up. It provides preliminary evidence that some physical performance measures (vertical jump and prone hold) can be improved with the neuromuscular warm-up compared to a traditional warm-up. It is recommended that the warm-up be included in regular training.
5	**The Effect of the NetballSmart Dynamic Warm-up on Isokinetic Knee Strength in Youth Netball Players** **Publication resulting from Chapter:** McKenzie, C.R., Brown, S.R., Whatman, C., Brughelli, M. (2019). The effect of the NetballSmart Dynamic Warm-up on isokinetic knee strength in youth netball players. *New Zealand Journal of Sports Medicine*: [in review].	**Purpose:** Determine whether the NetballSmart Dynamic Warm-up can improve isokinetic knee strength in youth netball players. **Rationale for the purpose:** Adequate knee strength is needed to perform successfully in netball given the demands of the game. The knee is also a common site of injury in netball and weakness about the knee is associated with several knee injuries in female athletes. There is currently no research investigating the effect of the NetballSmart Dynamic Warm-up on knee strength. **Approach:** Single group intervention. **Findings:** • The NetballSmart dynamic Warm-up did not improve knee peak torque or change angle of peak torque.

		• There were no significant changes found in the hamstring to quadriceps ratio. **Novel Contribution:** Evidence that when performed two to three times per week, the NetballSmart Dynamic Warm-up does not improve knee strength in youth netball players.
	Prelude to Chapter 6: Having investigated the effect of the NetballSmart Dynamic Warm-up, further evaluation was undertaken to consider the level of coach knowledge and their attitudes towards the warm-up and injury prevention in netball. Their experiences with the warm-up must be considered to provide further insight to assist the implementation of the programme.	
Section 3		
6	**Implementation of the NetballSmart Dynamic Warm-up: The Role of the Coach** **Publication resulting from Chapter:** McKenzie, C.R., Whatman, C., Walters, S., Brughelli, M. (2019). Implementation of the NetballSmart Dynamic Warm-up: The role of the coach. *International Sport Coaching Journal*: [submitted].	**Purpose:** Examine coach knowledge and attitudes towards injury and injury prevention in netball. Secondly, evaluate the experiences of the NetballSmart Dynamic Warm-up amongst coaches delivering the programme. **Rationale for the purpose:** Coaches are a key part in the successful implementation and sustainability of injury prevention programmes. Since the development of the NetballSmart Dynamic Warm-up in NZ there has been no research into the adoption and maintenance of the programme. **Approach:** Cross-sectional survey design using a mixed method approach. **Findings:** • Poor technique was perceived to be the most common injury risk factor in netball, and almost all coaches believed that a warm-up can reduce injuries. The ankle was correctly reported as the most common lower limb injury. • Experienced coaches or coaches who were also netball players did not have better knowledge of injuries. • Most coaches felt their personal coaching experience was sufficient to be able to coach the warm-up. • Most coaches reported observing improvements in player ability after using the warm-up. • A significantly higher proportion of coaches who were also netball players reported they would deliver the warm-up one to two times per week.

		• Regarding their experience of the NetballSmart warm-up three dominant themes were identified in the qualitative data: 1) the importance of coach education and understanding of injury prevention; 2) long-term player development; and 3) practical implementation of the NetballSmart Dynamic Warm-up. **Novel Contribution:** Initial coach feedback on the NetballSmart Dynamic Warm-up, as well as current coach knowledge and attitudes towards injury and injury prevention in netball, has been reported. The feedback from coaches was generally positive but highlighted some barriers to the translation of the programme into the netball environment which need to be addressed to ensure its success and sustainability.
7	**Discussion & Conclusion**	**Purpose:** To discuss the key findings across the thesis as a whole, summarise the novel contributions made, identify the limitations of the thesis and make recommendations for future research.

Section 1: Neuromuscular Warm-up Programmes and Physical Performance in Youth Athletes

Chapter 2: The Effect of Neuromuscular Warm-up Programmes on Physical Performance Measures: A Narrative Review

Overview

It is important to understand how neuromuscular warm-up programmes may affect modifiable factors that have been linked to both performance and injury risk. Adoption of these programmes by coaches and players is more likely to occur if evidence can be provided on their effectiveness in improving performance. The purpose of this narrative review was to examine the current literature relating to neuromuscular warm-up programmes in terms of performance enhancement. After a comprehensive literature search, 32 studies published between 2008 and 2018 were included in this review. Neuromuscular warm-up programmes have been shown to be effective at improving a number of physical performance measures in adult and youth team-sport athletes. Most of the research on this topic was conducted in male football players with little evidence in female athletes and other sports. Physical performance measures were also limited in studies involving female youth athletes. This comprehensive summary of the current knowledge regarding the effect of neuromuscular warm-up programmes on physical performance measures has highlighted gaps in the literature, providing recommendations for future research.

Introduction

Leading a physically active lifestyle is important in all age groups to promote fitness and health and reduce the risk of obesity and associated lifestyle diseases (5). However, the promotion of an active lifestyle and sports participation can lead to a greater risk of injury (5, 105). Injuries that occur as a result of sports participation are very common in modern western societies (105). Furthermore, treatment can be costly and time consuming (105). Sixteen years of injury surveillance data across 15 sports in the National Collegiate Athletic Association reported that more than 50% of all injures were to the lower body (56). Similarly, a study in high school athletes across nine different sports reported lower extremity injuries accounted for 53% of total injuries (29). The most common types of sports-related injury were sprains, strains and contusions, with ankle injuries the most common (29, 56). One injury that is a growing cause of concern is an Anterior Cruciate Ligament (ACL) injury which can result in a lengthy rehabilitation process causing absence from work or school and sport over a prolonged period of time (56). The highest incidence of ACL injury is seen in sports that involve pivoting movements such as football, basketball and handball. Furthermore, the incidence is up to 8 times higher among female athletes (5, 89). Therefore, despite the health benefits from sports participation, individuals are at risk of sports-related injury which can be specific to sport and gender (56). Injury prevention initiatives that address modifiable factors associated with performance and injury risk may contribute to lower injury rates (56).

Neuromuscular warm-up programmes have been found to reduce injury risk in adult (male) and youth (female and male) athletes in various sports, including football, basketball and handball (67, 76, 100, 124), with reported injury reductions of 30 to 50% (128). These programmes can be incorporated into training and game warm-up routines and require minimal, if any, additional equipment (51). Most programmes contain all, or a variation, of the following types of exercise: jogging or running, balance and stability, strengthening, agility, movement quality or technique (specifically jump/land) and plyometric exercises, and take between 15-30 minutes to complete (10, 70, 72, 107, 138). Some programmes also have increasing levels of difficulty for selected exercises to allow for progression within the warm-up. For example, the FIFA 11+ involves three levels of increasing difficulty in the exercises that focus on core and leg strength, balance, plyometrics and agility (10). However, implementation as intended (i.e. dosage, exercise selection/progression, setup) requires acceptance from coaches who may modify programmes to suit their coaching environment or not adopt the programme at all (71).

Even though various neuromuscular warm-up programmes have shown to be effective in reducing injury risk, the mechanisms of why injury is reduced are not clear. Physical performance measures including balance, proprioception, strength and movement quality have been linked to injury risk (3, 87, 101, 108). Therefore, these modifiable factors that can be related to both physical performance measures and injury risk could help to explain the positive effect of a neuromuscular warm-up programme. It is important to evaluate the effect of a neuromuscular warm-up on physical performance measures as this knowledge can help ensure appropriate exercise selection. In addition, a factor that is likely to influence the adoption and implementation of a neuromuscular warm-up programme by coaches and players is the possible performance-enhancing effect of such programmes (123, 136). As coaches are important to the successful implementation of injury prevention programmes, research showing performance benefits of neuromuscular warm-up programmes could help provide additional motivation for coaches to regularly deliver the programme to their players (132, 146). Therefore, the purpose of this review was to summarise the available scientific literature to investigate the effect of neuromuscular warm-up programmes on physical performance measures.

Methods

This review was conducted in accordance with published processes used to write a narrative review (49). An initial literature search was conducted in November 2015 with an updated search conducted in December 2018 using the following electronic databases: SportDiscus (EBSCOhost), Google Scholar, ScienceDirect and Ovid. Selected search terms and key words related to injury prevention, or neuromuscular warm-up, FIFA 11+ and Prevent injury and Enhance Performance (PEP) were combined in Boolean logic. Only full-text peer reviewed articles in English language were considered. Additionally, the reference lists of selected articles were screened for other relevant articles. To be included in the review, all studies had to be original research papers with a focus on evaluating the effect of a warm-up on physical performance measures. Additionally, the physical performance measures had to include at least one of balance, stability, power, strength, sprint, agility, movement quality or range of motion. Studies were excluded if they were expert opinion, critical commentary or review articles.

Findings

Thirty-two studies were identified as appropriate for inclusion in the review, two were within-group, pre-post studies (no control group), four were cluster randomised control studies, one was a randomised cohort study, and 25 were randomised control studies (all with a control group). A summary of the key characteristics of the included papers are presented in Table 4. All studies were published between 2008 and 2018 highlighting that, while the implementation of neuromuscular warm-up programmes is not new, research investigating the effect of such programmes on physical performance measures is a current trend. There were a total of 1458 participants, with a mean number of 46 participants, across the 32 studies. The largest study included 222 participants and the smallest study included 16 participants. All studies reported the mean age of included participants, with some controlled studies reporting the age for both intervention and control groups. The age range was 10-27 years with a mean age of 16.5 years. There were several different outcome measures reported, 13 studies included performance measures (e.g. jump, sprint, agility, balance, flexibility), 9 included strength or movement measures (e.g. isokinetic strength, motion analysis, joint range of movement, functional movement) and 10 included both types of outcome measures. The majority of studies evaluated the FIFA 11+ or a variation (*n*= 24), one study evaluated the PEP programme, and all other studies involved a general neuromuscular warm-up. Results of the studies varied with some studies finding an improvement in physical performance with the implementation of a neuromuscular warm-up, while other studies found no effect. Of the total studies, 78% reported some improvement in physical performance. Studies in adult athletes (≥18 years old) reported some improvement in 82% of studies, compared to 76% of studies in youth athletes (<18 years old).

Table 4. Summary of the key characteristics of included studies.

Study Author (year)	Study Design	Participants (analysed); gender; sport; age	Warm-up intervention; frequency; length; compliance (if stated)	Measures	Study Outcomes
Abedinzadeh et al. (2017)	RCT	*n*= 48; male; handball; 18.1 ±2.4 yr (INT); 17.5 ±3.1 yr (CON)	FIFA 11+; 8 weeks	Bosco Protocol (jump performance)	INT (within group): ↑ (p<0.001) in Bosco index & significant difference (between group) (p= 0.032)
Akbari et al. (2018)	RCT	*n*= 24; male; football; 16.8 ±1.2 yr	FIFA 11+; 3x per week; 8 weeks	VJH	INT (between group): ↑ (p= 0.002)
Ayala et al. (2017)	RCT, double baseline	*n*= 21; male; football; 16.8 ±0.7 yr	FIFA 11+ (level 2); 3x per week; 4 weeks	Dynamic postural control (Y-balance test); Single leg hop limb symmetry (single & triple hop distance); Sprint (10 & 20m); VJH (DJ); Agility (Illinois agility test) Joint ROM: Hip (passive straight leg raise test); Knee (Modified Thomas test); Ankle (weight-bearing lunge with knee extended test)	INT (between group): ↑ Y-balance (anterior & posteromedial); ↑ triple hop; ↓ 10 & 20m sprint times & ↑ VJH. No change in ROM
Bizzini et al. (2013)	Within-subject pre-post, double baseline	*n*= 20; male; football; 25.5 ±5.1 yr	FIFA 11+ (level 3)	Sprint (20m); Agility (T-test); VJH (CMJ & SJ); Stiffness (hop test); Balance (SEBT) Isometric knee ext: MVC; RFD	Differences between pre-post testing found for all dependent variables (P values 0.015 to <0.001), except MVC & RFD
Brito et al. (2010)	Within-subject pre-post	*n*= 18; male; football; 22.3 ±4.2 yr	FIFA 11+; 3x per week; 10 weeks; 73% compliance	Isokinetic knee strength: PT; con 60 & 180º/s; ecc 30º/s; ham/quad ratio (H:Q); Conventional H:Q & Dynamic control H:Q; (Hecc30º/s:Qcon180º/s)	INT (within group): ↑ (p<0.05) ham PT; con 60, 180 & ecc 30 (nondominant); con 60 (dominant) INT (within group): ↑ (p < 0.05) quad PT; con 60 & 180 (dominant)

					INT: Improvement ($p < 0.05$) H:Q; conventional H:Q 60 & dynamic control 60 (nondominant)
da Costa Silva et al. (2015)	RCT	*n*= 17; male; football; 18.3 ±1.6 yr	FIFA 11+ (week 1-3, level 1; week 4-6, level 2; week 7-9, level 3); 3x per week; 9 weeks; 85% compliance	VJH (CMJ & SJ)	INT (between group): ↑ ($p<0.01$) CMJ & SJ
Daneshjoo et al. (2012)	RCT	*n*= 36; male; football; 19.2 ±0.9 yr (INT); 19.7 ±1.6 yr (CON)	FIFA 11+; 2 months (x24 sessions)	Static balance (Stork test; eyes open [EO] & eyes closed [EC]); Dynamic Balance (SEBT) Proprioception test (bilateral, knee flex Biodex Isokinetic Dynamometer): 30, 45 & 60º/s	INT (within group): ↓ ($p<0.05$) Proprioception error (dominant); 45 ($p<0.01$) & 60 INT (within group): ↑ ($p<0.05$) Static Balance; EO & EC INT (within group): ↑($p<0.01$) SEBT No changes in CON group
Daneshjoo, Mokhtar et al. (2013)	RCT	*n*= 36; male; football; 18.9 ±1.4 yr	FIFA 11+; 3x per week; 8 weeks	Isokinetic knee strength: PT; con 60, 180 & 300º/s	INT (within group): ↑ ($p<0.05$) ham PT; con 60, 180 & 300 (dominant); 60 & 180 (nondominant) INT (within group): ↑ ($p<0.05$) quad PT; 300 (dominant) No changes in CON group Con ham strength was significantly different between INT & CON; dominant ($p= 0.01$) & nondominant ($p= 0.02$.)
Daneshjoo, Rahnama et al. (2013)	RCT	*n*= 36; male; football; 18.9 ±1.4 yr	FIFA 11+; 3x per week; 8 weeks	Isokinetic knee strength: PT; con 30, 60 & 90º/s	INT (within group): ↑ ($p<0.05$) ham PT; con 30 & 60 (dominant); 30 & 60 (nondominant) INT (within group): ↑ ($p<0.05$) quad PT; con 60 & 90 (dominant); 30, 60 & 90 (nondominant)

					No changes in CON group
DiStefano et al. (2010)	Cluster RCT	*n*= 46; male & female; football; 11male/ 11female (INT); 15male/ 9 female; (CON;) 10.0 ±1.0 yr	Traditional ACL Injury Prevention programme; 3x per week; 9 weeks; 80% compliance	VJH (CMJ); Dynamic balance (TTS)	INT (between group): ↓ (p = 0.003) TTS (anterior-posterior) INT (between group): ↑ (p = 0.04) CMJ
Gatterer et al. (2018)	RCT	*n*= 16; male; football; 10 yr	FIFA 11+; 2x per week; 5 weeks; 100%compliance	Standing long jump (distance); Body stability (S3 check, unstable uniaxial platform)	INT & CON (within groups): ↑ (p<0.001) stability; Likely greater improvements in INT compared to CON group; no effect on standing long jump performance
Impellizzeri et al. (2013)	RCT	*n*= 81; male; football; 23.7 ±3.7 yr (INT); 23.2 ±3.8 yr (CON)	FIFA 11+ (week 1-3, level 1; week 4-6, level 2; week 7-9, level 3); 3x per week; 9 weeks	Dynamic Balance (TTS); Sprint (20m); Agility (T-test); VJH (CMJ); Balance (SEBT); Core-stability (unstable seated balance) Isokinetic knee strength: PT; con 60 & 180º/s; ecc 60º/s	INT (between group): sig improved TTS & core-stability Possibly meaningful (between group) ↑ ham PT; ecc 60 & con 60 No sig difference for the other measures
Kilding et al. (2008)	RCT	*n*= 24; male; football;10.4 ±1.4 yr	The 11; 5x per week; 6 weeks; 72% compliance	Agility (Illinois agility test); VJH (CMJ); 3-step HJ; Sprint (20m); Core stability (prone hold)	INT (between group): ↑ (p= 0.001) CMJ; ↑ (p= 0.04) 3-step jump; ↓ (p= 0.008) sprint
Lim et al. (2009)	RCT	*n*= 22; female; basketball; 16.2 ±1.2 yr (INT); 16.1 ±1.0 yr (CON	Sports Injury Prevention Training Program (SIPTP); 8 weeks	3D motion analysis of a max effort rebound jump task: Jump height; Flexibility (Hip, knee, ankle [deg]); Muscle strength (hip abduction, ext, knee flex); Biomechanical measures (max knee flex angle, min inter-knee distance, max knee internal rotation angle, max knee ext moment, & max knee valgus moment)	INT (between group): ↑ strength & flexibility; ↑ knee flex angles (p= 0.02), ↑ knee distances (p= 0.01), ↓ H:Q (p= 0.02), ↓ max knee ext torques (p= 0.12) & higher max knee abduction torques (p= 0.04)

Lindblom et al. (2012)	RCT	*n*= 41; female; football; 14.2 ±0.7 yr (INT); 14.2 ±1.1 yr (CON)	Neuromuscular warm-up; 2x per week; 11 weeks	Balance (SEBT); VJH (CMJ); Triple hop (distance); Agility (T-test); Sprint (10 & 20m)	No significant effect of the intervention was found for any of the performance measures between INT & CON groups
Lopes et al. (2018)	RCT	*n*= 71; male; futsal; 27.0 ±5.1 yr (INT); 26.0 ±5.1 yr (CON	FIFA 11+ (4 weeks at level 3); 2x per week; 10 weeks	Agility (T-test); Sprint (30m); Flexibility (sit-and-reach); VJH (SJ)	No significant effect of the intervention was found for any of the performance measures between INT & CON groups
Oliano et al. (2017)	RCT	*n*= 21; female; handball; 12.9 ±0.8 yr (INT); 13.2 ±0.9 yr (CON)	FIFA 11+; 2x per week; 12 weeks	Postural balance (computerised dynamic posturography) Isokinetic knee strength: PT; con 60º/s	INT (within group): ↑ ($p<0.05$) postural balance Both INT & Con ↑ PT
Otsuki et al. (2014)	RCT	*n*= 60; female; basketball; 13.1 ±0.8 yr (INT): 13.1 ±0.8 yr (CON)	Injury Prevention Programme; 2x per week; 6 months	2D motion analysis of a vertical DJ (left leg): Knee valgus motion; Knee flex angle; Knee flex ROM	CON (between group): ↑ ($p<0.001$) knee valgus motion; ↓ ($p<0.001$) knee flex ROM INT: No change to knee valgus motion or knee flex ROM
Pasanen et al. (2009)	Cluster RCT	*n*= 222; female; floorball; 24.2 ±4.2 yr (INT); 23.3 ±5.3 yr (CON)	Neuromuscular warm-up; 1-3x per week; 6 months; 60% compliance	VJH (static jump & CMJ); Jumping over a bar (number of jumps in 15s); Standing on a bar (number of balance losses in 60 s); Figure-8 running (10m)	INT (between group): ↑ ($p= 0.003$) number of jumps over a bar; ↓ ($p= 0.05$) number of balance losses
Pomares-Noguera et al. (2018)	RCT, double baseline	*n*= 23; male; football; 11.8 ±0.3 yr	FIFA 11+ Kids; 2x per week; 4 weeks	Dynamic postural control (Y-balance); Sprint (20m); Agility (Illinois Agility Test); VJH (DJ & CMJ); HJ; Football skills (slalom dribble & wall volley test) Joint ROM: Hip (passive straight leg raise test); Knee (Modified Thomas test); Ankle (weight-bearing lunge with knee extended test)	INT (between group): ↑ ($p<0.05$) Y-balance; VJH (CMJ & DJ) & HJ. CON (between group): ↓ 20 m sprint; ↑ number of correct rebounds (wall volley test). INT (between group): ↑ knee flex ROM, possibly beneficial effect

Reis et al. (2013)	Randomised Cohort	*n*= 36; male; futsal; 17.3 ±0.7 yr	The FIFA 11+; 2x per week; 12 weeks	VJH (CMJ & SJ); Sprint (5 & 30m); Agility (T-test); Balance (SL flamingo-test); Football skills (slalom dribble test) Isokinetic knee strength: PT; con 60 & 240º/s; ecc ham 30º/s H:Q (Hecc30º/s:Qcon240º/s)	INT (between group): ↑ ($p<0.05$) quad PT; con 60 (dominant); con 60 (nondominant); H:Q ratio (dominant) INT (between group): ↑ ($p<0.05$) ham PT; con 60; ecc 30 (dominant); ecc 30 (nondominant) INT (between group): ↑ ($p<0.05$) SJ; CMJ; ↓ ($p<0.05$) sprint 5m & 30m; agility; slalom performance INT (between group): ↑ ($p<0.05$) balance by ↓number of falls (nondominant).
Rey et al. (2018)	RCT	*n*= 23; male; football; 24.9 ±3.7 yr (INT); 24.6 ±3.1 yr (CON)	FIFA 11+; 3x per week; 6 weeks	Functional Movement Screen (FMS)	No significant effect of the intervention was found for the FMS between INT & CON groups
Robles-Palazon et al. (2016)	RCT	*n*= 21; male; football; 16.4 ±1.3 yr	FIFA 11+; 3x per week; 4 weeks	Balance (Y-balance); Sprint (10 & 20m); VJH (DJ) Joint ROM: Hip (passive straight leg raise test); Knee (Modified Thomas test); Ankle (weight-bearing lunge with knee extended test)	No significant effect of the intervention was found for any of the performance measures between INT & CON groups
Rossler et al. (2015)	Cluster RCT	*n*= 122; male & female (4.9%); football; 10.0 ±1.8 yr (INT); 10.1 ±1.6 yr (CON)	FIFA 11+ Kids; 2x per week; 10 weeks; 85.3% compliance	Single leg stance (centre of pressure, balance system); Balance (Y-balance); VJH & reaction (DJ & CMJ); HJ; Sprint (20m); Agility; Football skills (slalom dribble & wall volley test)	INT (within group): Likely beneficial effect: Y-balance (right leg) & agility run. INT (within group): Possibly beneficial effect: Y-balance (left leg), DJ reactive strength, VJH & HJ, slalom dribble & wall volley test. INT (between group): better performance in agility & CMJ

Sahin et al. (2018)	RCT	*n*= 20; basketball; 10.7 ±10.3 yr	FIFA 11+; 3x per week; 10 weeks	VJH; Agility (Pro-agility test)	INT (within group): ↓ (p<0.05) agility. No change in VJH
Steffen et al. (2008)	RCT	*n*= 31; female; football; 17.1 ±0.8 yr	The 11; 3x per week; 10 weeks	VJH (DJ, CMJ & 15s continuous rebound jump test); Sprint (40m); Football skills (speed dribbling/shooting distance) Isokinetic knee strength: PT; con 60 & 240º/s; ecc 30º/s H:Q 60º/s; Isometric knee strength: PT; 30, 60 & 90º knee flex; Isometric hip strength 2D motion analysis of VJ: frontal plane peak knee angles	No significant effect of the intervention was found for any of the performance measures between INT & CON groups
Taylor et al. (2018)	RCT	*n*= 97; basketball & football; 15.4 ±1.0 yr (INT); 15.7 ±1.6 yr (CON)	Neuromuscular warm-up; 2-3x per week; 6 weeks; 66% compliance	3D motion analysis of hip & knee during jump landing tasks: Peak joint angles; Joint angular excursions (absolute value peak angle - angle at initial contact); Peak external joint moments	No significant effect of the intervention was found for any of the performance measures between INT & CON groups
Thompson et al. (2017)	RCT	*n*= 46; female; football; 11.8 ±0.8 yr (INT); 11.2 ±0.6 yr (CON)	FIFA 11+; 2x per week; 8 weeks (total 15 sessions); 70.2% compliance	Peak knee valgus moment during: Pre-planned cutting; Unanticipated cutting; Double-leg jump; Single-leg jump	INT (between group): ↓ (p= 0.034) peak knee valgus moment during double-leg jump.
Vescovi & VanHeest (2010)	RCT	*n*= 31; female; football; 15.7 ±1.2 yr (INT); 16.8 ±0.4 yr (CON)	Prevent Injury Enhance Performance Programme (PEP); 3x per week; 6 weeks; 92% compliance	Sprint (9.1, 18.3, 27.4 & 36.6m); VJH (CMJ); Agility (Illinois & Pro-agility tests)	INT (between group): ↓ (p≤0.025) 27.3 & 36.6m sprint times No changes for other sprint times or CMJ; agility (Illinois & pro-agility) tests ↑ time in both groups.
Zarei, Namazi et al. (2018)	RCT	*n*= 42; football; 12.1 ±1.8 yr (INT); 12.3 ±1.1 yr (CON)	FIFA 11+ Kids; 3x per week; 10 weeks	Agility (Illinois agility test); Flexibility (sit-and-reach); HJ; Triple hop (distance); Balance (Y-balance); Sprint (20 & 40 yard);	INT (between group): ↑ (p= 0.001) Y-balance; (p= 0.002) triple hop & (p= 0.002)

				Football skills (slalom dribble test); Prone Hold (front & side prone) Isokinetic knee strength: PT; con 60 & 90º/s	INT (between group): ↑ quad & ham PT
Zarei, Abbasi et al. (2018)	Cluster RCT	*n*= 66; male; football; 15.6 ±0.5 yr (INT); 15.8 ±0.7 yr (CON)	FIFA 11+; 2x per week; 30 weeks	Agility (Illinois agility test); Sprint (9.1 & 36.6m); Yo-Yo Intermittent Recovery Test (Level 1); Lower body anaerobic power (Bosco CMJ 15s); VJH (Sargent Jump); Flexibility (sit-and-reach); Football skills (dribbling sprint)	INT (between group): ↑ (p<0.001) VJH; (p= 0.02) Bosco CMJ INT (between group): Very likely beneficial effect: agility INT (between group): Possibly beneficial effect: 9.1m sprint CON (between group): Possibly harmful effect: dribbling test
Zebis et al. (2016)	RCT	*n*= 40; female; football & handball; 15.9 ±0.4 yr (INT); 15.6 ±0.75 yr (CON)	Neuromuscular warm-up; 3x per week; 12 weeks	3D motion analysis of a side-cutting movement (at initial contact): Maximal knee joint valgus moment; Knee valgus angle; Isometric knee extensor strength	No significant effect of the intervention was found for any of the performance measures between INT & CON groups

INT=intervention group; CON=control group; RCT=randomised control trial; ↑=increase; ↓=decrease; º/s= degrees per second; yr=years; ham=hamstrings; quad=quadriceps; ext=extension; flex= flexion; con=concentric; ecc=eccentric; VJ= vertical jump; VJH=vertical jump height; DJ=drop jump; ROM=range of motion; CMJ=countermovement jump; SJ=squat jump; SEBT= star excursion balance test; HJ=horizontal jump; MVC=maximal voluntary contraction; RFD=rate of force development; PT=peak torque; TTS=time-to-stabilisation

Discussion

1. Performance measures

1.1 Adult athletes

Several studies (*n*= 6) have investigated the effect of a neuromuscular warm-up on performance measures in adult athletes (≥18 years old) (1, 10, 18, 20, 65, 77, 107). All of these studies have investigated the FIFA 11+ in male athletes, except one that tested a general neuromuscular warm-up programme in female athletes (107). Of these seven studies, one study was in handball, one study was in futsal, four studies were in football, and the study involving female athletes was in floorball. Measures of core stability and time-to-stabilisation improved when the FIFA 11+ was performed three times per week (9-week intervention) in amateur male football players (23.7 ±3.7 years) (65). In professional male football (18.3 ±1.6 years), the FIFA 11+ was also found to significantly improve jump performance (11-13%) (18). Of note, the intervention duration, frequency, intensity and progressions across levels were the same in both studies. A strength of both studies was the comparison of the FIFA 11+ with a control group that followed a 'normal' football warm-up for the same duration as the intervention. Similar improvements in jump performance were also found in another study of similar male footballers using the FIFA 11+ (level 3), however there was no control group (10). An eight-week FIFA 11+ programme significantly improved the Bosco index score (a series of lower body jump exercises) in male handball players (18.1 ±2.4 years) (1).

Similar measures of jump and balance performance have been shown to improve after a longer intervention (six months) in professional female floorball players (24.2 ±4.2 years) with the implementation of a neuromuscular warm-up programme comparable to the FIFA 11+ (i.e. the programme consisted of four different types of exercises performed at low to moderate intensity for 20 to 30 minutes: 1) running technique; 2) balance and body control; 3) jumping; and 4) strengthening of the lower limbs and trunk) (107). This was the largest study in the review (*n*= 222) and reported jumping over a bar (maximum number of jumps in 15s) and standing single leg on a bar (number of balance losses in 60s) both significantly improved (107). Static and dynamic balance improved in male football players (19.2 ±0.9 years) after 24 sessions of the FIFA 11+ over two months. However, even though this study included a control group, only within-group changes were reported. In contrast, a more recent study in male futsal players (27 ±5.1 years) found no performance enhancement after performing the FIFA 11+ two times per week for 10 weeks (four weeks at level 3) (77). No improvement was found for sprint (30 m), agility (T-test), flexibility and jump measures compared to a control group. While it is difficult to compare studies due to the differences in sports and performance tests investigated, out of the mentioned studies that reported frequency (times per week) of performing the FIFA 11+, this study performed the warm-up twice per week compared to three times per week. Thus, the lower weekly frequency may not have been enough to elicit improvements in this group of athletes, even though the implementation recommendations for performing the FIFA 11+ is a minimum of twice per week.

1.2 Youth athletes

Numerous studies (*n= 20)* have investigated the effect of various neuromuscular programmes in younger athletes (10-18 years) (2, 4, 23, 45, 66, 70, 72, 99, 103, 109, 118, 120, 121, 131, 138, 143, 148, 154-156). A modified version of the FIFA 11+ ("FIFA 11+ Kids") has been developed which focuses on enhancing coordination and balance, strengthening the leg and core muscles, and improving landing technique, improved physical performance in football players aged 10-12 years, compared to a traditional warm-up (109, 120, 155). Likely beneficial or significant improvements were found in balance (Y-balance), agility, triple hop for distance and speed after performing the warm-up two to three times per week, for 10 weeks (120, 155). Additionally, a recent study by Pomares-Noguera and colleagues (2018) suggested that performing the same FIFA 11+ Kids warm-up for just four weeks can improve balance (Y-balance), agility, vertical and horizontal jump performance in male youth football players (11.8 ±0.3 years).

An earlier version of the FIFA 11+, "The 11", has also been shown to improve lower body power (countermovement jump [CMJ] and 3-step horizontal jump) and sprint speed in youth male football players (10.4 ±1.4 years) (66). This programme was performed five times per week which may question its suitability for implementation in a real-world context. In a realistic school or community sport environment, practice is generally one to two times per week with a game, so at most athletes would perform the warm-up three times per week. When performed only three times per week "The 11" did not produce any differences in performance compared to a control warm-up in a study of older female football players (17.1 ±0.8 years) (131). Additionally, a similar neuromuscular warm-up programme did not produce improvements in another group of youth female football players (14.2 ±0.7 years) when performed twice per week (72). Similarly, the PEP Programme did not improve CMJ or agility in female youth footballers (15.7 ±1.2 years) but did improve sprint performance over 20-30 m (148). These findings suggest there may be differences between the effect of neuromuscular warm-up programmes on male and female athletes in the youth age group. A possible reason for the absence of positive effect may be due to the lack of necessary stimulus required to promote changes and enhance performance in youth female athletes compared to males (72).

Improvements in performance after following the FIFA 11+ two to three times per week have been reported in male youth futsal and football players (2, 4, 114, 154). Irrespective of the frequency or length of the intervention, increases in vertical jump height (CMJ and squat jump [SJ]) were reported in all studies (2, 4, 114, 154). Ayala et al. (2017) also found improvements in single leg exercises, including leg symmetry of a single leg triple hop and balance (Y-balance). Furthermore, both Ayala et al. (2017) and Reis et al. (2013) found improvements in sprint performance. The FIFA 11+ has also been shown to improve agility and game-specific skills in youth male football players, suggesting the warm-up can contribute to technical performance as well as physical performance of team-sport athletes which could be investigated in future research (114). The longer intervention study by Zarei et al. (2018) (30 weeks) also reported an improvement in agility with possible beneficial effects in sprint performance, suggesting there were positive long-term effects of the implementation of the FIFA 11+ on performance in youth male football players (15.6 ±0.5 years). In contrast to these studies, Robles-Palazon et al. (2016) found no meaningful differences in comparison to a control group in balance (Y-balance), sprint (10-20 m) and vertical drop jump height in a similar group of male youth footballers with similar intervention parameters. In a slightly younger participant group (10.7 ±10.3 years), the FIFA 11+ significantly improved agility in basketball players; however, when compared to a control group there were no differences observed (121). Furthermore, the FIFA 11+ showed significant improvements in balance, but no change in horizontal jump in 10-year-old male football players with a reported 100% compliance rate (45). The FIFA 11+ was found to improve postural balance of young female handball players (12.9 ±0.8 years) (99). Similarly, a traditional ACL neuromuscular warm-up was shown to improve time-to-stabilisation and vertical jump height in both male and female youth football players(10.0 ±1.0 years) (23). Overall, there is conflicting evidence as to the effect of a neuromuscular warm-up programme on physical performance in youth athletes from the ages of 10 to 17 years. The reviewed studies are difficult to compare due to differences in physical performance measures, duration and frequency of the intervention programmes.

2. Strength and movement quality

2.1 Adult athletes

The effect of the FIFA 11+ on lower limb strength has also been investigated in adult athletes. Lower limb strength, particularly about the knee, is important in performance and reduction of injury risk (101). Isokinetic hip and knee strength (concentric and eccentric) have been measured in various studies with adult male football players (13, 19, 21, 65). Concentric quadriceps peak torque (PT) and concentric and eccentric hamstrings PT has been reported to significantly increase within a group (no control) after 10 weeks of performing the FIFA 11+ three times per week (13). Similarly, concentric quadriceps and hamstrings PT was found to significantly improve in a group using the FIFA 11+ compared to a control group after eight weeks (19, 21). Furthermore, improvements were also found for eccentric and concentric hamstring PT, but from a practical point of view these increases were only possibly meaningful (65). A significant improvement in hamstrings to quadriceps ratio (H:Q) has also been reported in male football players (13). These improvements in hamstring and quadriceps PT are likely one of the main mechanisms underlying the injury reductions linked to the implementation of the FIFA 11+. Therefore, exercises that target quadriceps and hamstring strength, such as the Nordic hamstring exercise, are considered important inclusions in the warm-up (19).

Other than improvements in strength, another key proposed mechanism for the reduced injury rate associated with the use of neuromuscular warm-ups is better movement quality. To our knowledge, there has only been one study published that has investigated the effect of the FIFA 11+ on movement quality as measured by the Functional Movement Screen (FMS) (115). This study found that the FIFA 11+ did not produce significant improvement in the FMS score suggesting the implementation of the FIFA 11+ may not produce additional improvements in fundamental movement patterns compared to those achieved in a regular warm-up (115). Alternatively, it may be that the jump/land and change of direction movements targeted in the FIFA 11+ are not well assessed by the FMS. Further research is needed to investigate whether movement quality can be improved with the FIFA 11+ and similar neuromuscular warm-up programmes. Additionally, all the above studies involved male football players highlighting there is a need for further research on female athletes and other sports.

2.2 Youth athletes

In comparison to studies involving adult athletes, there have been only a few studies that have measured strength in youth athletes to evaluate the effect of a neuromuscular warm-up programme (99, 114, 131, 155). There were no differences in isokinetic or isometric strength found between intervention and control groups in youth female football players following the implementation of the FIFA 11 (99, 131). In contrast, studies of the FIFA 11+ and FIFA 11+ Kids reported improvements in concentric quadriceps PT and concentric and eccentric hamstrings PT, as well as improvements in H:Q ratio in youth male futsal and football players (114, 155). These contrasting findings could highlight the differences in physiological and hormonal changes between boys and girls during puberty and how this affects strength gains in this age group (43).

Improvements in fundamental movement mechanics and neuromuscular training may help to reduce injury risk in young athletes (43). Neuromuscular control deficits, in particular, poor hip, knee, and ankle alignment during jump-landing tasks are especially common in prepubescent athletes (43). Therefore, neuromuscular training programmes are important in this group of athletes to help correct potentially injurious lower-limb alignment (43). Furthermore, female adolescents have slower neuromuscular control development during puberty compared to males (43, 53). Of particular concern is the increased incidence of ACL injury after puberty in female athletes, potentially due to this poor neuromuscular control (103). As a result, a number of studies have investigated the effect of a neuromuscular warm-up programme on jump/landing technique in female youth athletes (70, 103, 131, 143, 156). Basketball players (16.2 ±1.2 years years) were found to significantly improve flexibility (hip and knee flexion, ankle dorsiflexion), muscle strength (hip abduction/extension and knee flexion PT) and some biomechanical measures associated with ACL injury risk (maximum knee flexion angle, minimum inter-knee distance, maximum knee extension moment, maximum knee valgus moment and H:Q ratio) during a jump rebound task after eight weeks of a neuromuscular warm-up programme (sports injury prevention training programme) (70). Similarly, peak knee valgus significantly decreased between intervention and control groups during a double-leg jump after eight weeks of the FIFA 11+ in a group of female football players (11.8 ±0.8 years) (143). Therefore, there is some evidence the FIFA 11+ may reduce the risk of ACL injury during jumping tasks in youth athletes. In contrast, no changes in knee valgus or knee flexion motion were found during a vertical drop jump following a similar neuromuscular warm-up programme in female basketball players (13.1 ±0.8 years); however, both measures worsened in the control group suggesting the warm-up programme limited the loss of knee control in female athletes during puberty (103). Additionally, a neuromuscular warm-up programme did not produce improvements compared to a control group in biomechanical risk factors during side-cutting movements or vertical drop jumps in youth football and handball players (131, 156). Furthermore, a three-dimensional motion analysis of various jump landing tasks after six weeks of a neuromuscular ACL injury prevention programme in youth athletes (gender not stated) (15.4 ±1.0 years) concluded there were no significant biomechanical changes relative to the control group; however, adherence was reported to be only 66% in this study (138).

As poor jump/landing technique is considered common in youth female athletes, most published studies in this population have measured associated biomechanical factors with a limited number of studies focused on performance measures. Additionally, the majority of these studies were performed in football athletes (72, 133, 143, 148). Further research investigating the effect of a neuromuscular warm-up on other physical performance measures in youth females and other sports is needed. Finally, there have been a few studies that have investigated joint range of movement (ROM) after a neuromuscular warm-up programme in youth football players (4, 109, 118). Joint ROM was measured by passive hip flexion (passive straight leg raise test), knee flexion (Modified Thomas test), and ankle dorsiflexion (weight-bearing lunge with knee extended test). There were no meaningful differences found between a control warm-up and FIFA 11+ for all joint ROM measures following four weeks of the programme (4, 118). However, a possibly beneficial effect of the FIFA 11+ Kids on knee ROM has been reported (109). As the FIFA 11+ and FIFA 11+ Kids do not include exercises specifically to enhance joint ROM (such as a series of more dynamic stretches), the lack of improvements in the joint ROM measures may not be unexpected (4, 109, 118).

Conclusion

Neuromuscular warm-up programmes have been shown to be effective at improving a number of physical performance measures in adult and youth team-sport athletes. However, with the majority of research conducted in male football players, there is limited evidence in female athletes and other sports that could benefit from the implementation of these programmes. Further evidence of the performance benefits in these groups may enhance the acceptance from coaches and players, increasing adoption of the programmes. Additionally, studies involving female youth athletes have mainly focused on biomechanical changes and movement quality during jump/landing tasks with little research investigating other physical performance measure (e.g. jump, speed, strength). Further research addressing these gaps in the literature is recommended.

Chapter 3: Performance Profiling of Female Youth Netball Players

This chapter comprises the following paper published in *Journal of Strength and Conditioning Research.*

Reference:

McKenzie, C.R., Whatman, C., Brughelli, M. (2019). Performance profiling of female youth netball players. *Journal of Strength and Conditioning Research:* [E-pub Ahead of Print].

Overview

The purpose of this study was to investigate the physical performance characteristics of New Zealand secondary school netball players to provide a physical performance profile and determine if there were differences between playing grade and playing positions for this group. A total of 102 female netball players (mean ±SD: age 13.3 ±0.50 y, height 166.95 ±5.72 cm, body mass 60.94 ±12.80 kg) participated in this study. Measurements included anthropometry, horizontal and vertical jump performance, balance, core strength, change of direction speed and split sprint times. Magnitude-based inferences were used to determine differences in all measures. Grade one players jumped further and higher (ES= 0.41 to 1.37) and ran faster with small to moderate differences. They demonstrated faster change of direction speed (ES= -0.73 to -1.31), greater core strength (ES= 0.28 to 1.17), and a faster time-to-stabilisation (ES= -0.69). Grade two circle players jumped further (ES= -0.29), compared to non-circle players who jumped higher (ES= 0.35). Non-circle players had faster sprint and change of direction speed (ES= -0.33 to -0.55) and measures of balance (ES= -0.47 to 0.55). Grade one circle players were found to be faster over 20 m (ES= 0.75). The results of this study showed differences in the physical performance capabilities between youth netball players competing in different grades, as well as differences between playing positions. These findings have provided a physical performance profile of female youth netball players in New Zealand, suggesting that physical performance measures could be used for position-specific training and talent identification and selection.

Introduction

Netball is an intermittent team sport that is popular among females in the commonwealth countries, with more than 145,000 affiliated players in New Zealand (NZ) alone (17, 91). It is a highly physical non-contact sport requiring speed, anaerobic power, changes of direction, abrupt deceleration, jumping and landing; as well as tactical awareness and ball skill (44). Netball is played on a court 30.5 m x 15.25 m which is split into thirds (17). The thirds create spatial restrictions subsequently influencing the task constraints for each of the seven positions on court (17). Task constraints, including rebounding, guarding, off-ball guarding, defending, sprinting, jogging and shuffling, for each position have been shown to influence the physiological demands and activity profiles of adult players during a game of netball (36). The seven positions in a game of netball include mid-court positions (centre (C), wing attack (WA), wing defence (WD)), shooting positions (goal shoot (GS), goal attack (GA)), and defence positions (goal keep (GK), goal defence (GD)). Positional groups in this study were divided into circle (GK, GS, GA, GD) and non-circle (C, WA, WD) players.

The physiological demands placed on players in various sports and across different positions is of interest to strength and conditioning coaches. Information regarding sport and position specific requirements can be applied directly by strength and conditioning coaches to assist them in the design and implementation of training programs, to ensure athletes are prepared to withstand the physical requirements and perform successfully in a game (6, 142). Several studies have reported the physiological demands and activity profiles of adult netball players (6, 17, 22, 35, 36, 137). Video footage and a supporting computer analysis system has been used to measure specific netball movements during a game of netball (22, 36). It was found that mid-court players (GD/WD/C/WA/GA) performed more jogging, running and sprinting activities compared to predominant circle players (GS/GK) (36). The C position also travelled further and had the highest mean percentage time spent in active activity than both GK and GS positions (22, 36). It was also found that GS performed far less jumps (vertical) than any other position (36). Other studies have used accelerometers or a radio frequency-based athlete tracking system to measure player load and movement frequency in netball (6, 17, 35, 137). The position with the greatest player load was found to be C (6, 17, 35) with GS having the lowest player load than all other positions (17, 35), as well as performing movement combinations that were very different to all the other positions (137). The greatest contributor to total match load for C was jogging, compared to shuffling for GS (6). The C position was also found to have the greatest level of activity in all planes of movement. Pairwise comparisons between playing positions of elite-level netball players found that GD and GS were most dissimilar, with only the WA, GA and GD playing positions being closely related (137). Additional research between playing positions has also been conducted in other intermittent team sports, such as rugby league and soccer (41, 47). It has been shown that there are specific roles in team sports, and these roles have position-specific game demands; therefore, the need for position specific components in training and strength and conditioning is important to ensure player success (36).

Knowledge of sport-specific game-demands can help to create performance profiles for different sports, as each sport and its' positions could be seen to be characterized by a different athletic profile (47). The use of physiological and anthropometric assessments of athletes to build physical performance profiles has been investigated in several sports, including netball (126), rugby league (40, 41), football (47, 78), Australian rules football (116) and volleyball (38). Furthermore, it has been suggested that performance profiles could assist with team selection or talent identification of athletes, as well as determining starting and non-starting players (i.e. players selected to participate in a team or starting line-up) (40, 78, 126). Typically, physiological and anthropometric measures have also been found to improve with an increase in playing level (38, 41, 126). Knowledge of the differences in physical characteristics between junior and senior players could impact junior athlete development (126). Significant differences were found in physiological measures between junior elite and sub-elite rugby league players (40). Junior elite players were found to be superior in speed, change of direction speed, vertical jump height and estimated maximal aerobic capacity (VO_2max) compared to their sub-elite counterparts. Elite Australian netball players were found to be significantly taller, faster and had superior lower leg power and greater running capacity than lower playing levels (sub-elite, regional, under 19 and under 17) (126).

Despite the importance of physical qualities for match performance, there are limited studies investigating physical profiles in youth netball, specifically in NZ. Physiological and anthropometric differences have been found across three age categories in a regional netball academy in the United Kingdom (141), and height, body mass and physical characteristics have been shown to differ between positions in youth netball (142). Additionally, Thomas et al. (2016) have reported some initial normative performance data for youth female netballers. Therefore, the purposes of this study were to provide a physical performance profile and determine if there are differences between level of performance (playing grade) and/or playing positions (circle versus non-circle players) in NZ secondary school netball players. There is currently limited data on this topic and identifying performance profiles and positional demands could potentially assist with selection, training, coaching and player development.

Methods

Experimental approach to the problem

A cross-sectional study design was used to investigate physical performance measures in female youth netball players. This was achieved by conducting various physical performance tests and determining differences between playing grade and playing position. All testing was conducted during the early competitive phase of the netball season. All testing was conducted on-site at the involved secondary schools, with an average of 90 minutes to complete the testing battery. The location, time constraint and previous studies influenced the selection of tests included in the field-testing battery.

Subjects

A total of 102 female youth netball players (mean ±SD: age 13.3 ±0.50 y, height 166.95 ±5.72 cm, body mass 60.94 ±12.80 kg) participated in this study. Participants were recruited through local secondary schools. All participants were training and competing in a secondary school netball program and were healthy and free from injury in the last six months. As the structure of the netball program was similar for all grades, the participants were involved in netball-specific training twice a week with one competitive game. Training and game duration were the same for all participants. The participants had no previous resistance or neuromuscular training. Prior to participation, all participants were informed of the benefits and risks of the investigation before signing an institutional approved informed assent document to participate in the study. As all participants were under the age of 18 years, parental or guardian consent was also required by signing an institutional approved informed consent document. This study was approved by the Auckland University of Technology Ethics Committee.

Procedures

The selected measures and corresponding tests for this study were balance (Modified Star Excursion Test), split sprint times (2 to 20 m straight line sprint), change of direction speed (T-test), vertical and horizontal jump performance, core strength (prone hold), and lower body dynamic stability (time-to-stabilisation (TTS) landing). In addition, body mass, height, playing position and playing level were recorded. Participants performed a 10-minute standardised warm-up that replicated a generic netball warm-up, consisting of jogging, fast dynamic movement (butt kicks, high knees, side-step, grape-vine), slow dynamic movement (variation of bodyweight squats, lunges, hurdle walk, leg swings), and finished with low-intensity sprint drills and low volume plyometric exercises (vertical and horizontal jumps). They were then split into groups as the testing battery followed a rotational format; therefore, we did not control for the order of exercises. Three recorded trials were performed at each testing station after warm-up and test familiarisation and the best of these three trials was used for analysis. All tests were selected due to their relevance to common game-related activity and movements that have been identified during a game of netball (36).

Vertical Jump

An AMTI portable force plate (Advanced Mechanical Technology, Inc. Watertown, MA) was used to assess vertical jump height (400 Hz sampling rate). Participants were required to stand in the centre of the force plate with their feet hip width apart and hands on their hips. They were then asked to perform a maximal countermovement jump (CMJ), jumping and landing on two feet, keeping their lower limbs extended during the flight phase of the jump. Participants were allowed three familiarisation jumps before data was collected. Jump height was then determined by finding the total flight time in a custom-made LabVIEW program (National Instruments, 2014, Auckland, NZ) and inserting into an equation previously used by Moir (2008). The equation is as follows: time in the air jump height = $1/2\ g\ (t/2)^2$, where $g = 9.81$ m sec^{-2} and t = time in air (85). Participants performed three trials with 30 seconds rest between trials.

Horizontal Jump

Participants were asked to stand with their feet flat on the ground with their toes behind a line marked perpendicular to a measuring tape (0 cm mark). They were then asked to jump as far forward as possible, using arm swing and landing on both feet. The participants were required to stick their landing and stay in the end position until the measurement had been taken. Three familiarisation jumps were allowed to ensure they applied the correct movement pattern. Jump distance was measured from the start line (0 cm mark) to the heel of the back foot upon landing. If participants did not stick the two-foot landing it was considered a "non-jump" and they were required to repeat the jump until three successful jumps were recorded, with 30 seconds rest between trials.

Time-to-stabilisation

Similar to previous methods (119), participants were first assessed for a two-foot maximal vertical jump height using a Vertec (Swift Performance Equipment, Queensland, AUS) which was placed directly over the centre point of an AMTI portable force plate (Advanced Mechanical Technology, Inc. Watertown, MA). Once maximum jump height had been established, the plastic fingers of the Vertec were set at 50% of this value. This created an individual jump height target to control for jump height during each TTS test (119). To begin the TTS test, the participants were asked to stand behind a marked line 20 cm back from the centre of the force plate. Then, applying a two-footed CMJ, they were asked to jump and reach their individual jump height target with their fingertips and land single legged on their right foot with their hands on their hips. The participant had to stabilise and assume this balanced landing position as quickly as possible without any additional motion (i.e. hopping, swaying or letting the left foot touch the force plate). They were required to hold this stabilised position for 10 seconds. If a participant fell or lost balance the test was repeated. Participants were allowed at least three familiarisation jumps before data collection. Participants were required to repeat the jump until three successful jumps were recorded, with 30 seconds rest between trials. The time-to-stabilisation was determined in a custom-made LabVIEW program (National Instruments, 2014, Auckland, NZ) from the time of initial landing contact until they stabilised within 5% of their body mass (144).

Prone Hold

Participants assumed a prone hold position with their elbows and forearms on the ground, hands grasped, feet approximately hip width apart, head facing towards the ground and body straight with no arching or bowing in the lower back. The participant was required to maintain this position for as long as possible. The test was stopped if the participant excessively arched or bowed their lower back. The maximum time the participant maintained a correct position was recorded. This test was performed once.

Speed

Split sprint times were measured with a Radar Gun (Stalker ATS II, Applied Concepts Inc., Richardson, TX) across distances of 2, 5, 10, 15 and 20 m. Participants were asked to start from a still, split stance position 2 m directly in front of the radar gun. Participants were encouraged to sprint as fast as they could for each trial, completing a total of three recorded trials. Data was then cut using the Stalker ATS II software program (Version 5.0). In each trial, an acceleration run was determined by eliminating any data that had a zero value and by cutting each trial at the point where speed began to decrease. All cut files were then analysed in a custom-made LabVIEW program (National Instruments, 2014, Auckland, NZ) to find split times at each distance.

Change of direction speed

A T-test was used to measure change of direction speed (122). A different change of direction test has been used in previous netball literature (141, 142); however, this test was chosen as the movements required to complete the test are very similar to the physical movement demands of netball, including forward sprinting, side shuffling (left and right), and backpedalling (36). Cones were set up to resemble a ‘T’ shape. A marked start/finish line with timing gates, placed at approximate hip height for all participants, (Swift Performance Equipment, Queensland, AUS) was set up on court. The test started by sprinting forward, activating the timing gates, to the top of the T (5 m). From there participants side-shuffled to the left (5 m), back to the right past the centre cone (10 m), shuffled left again back to the centre cone (5 m), and then backpedalled through the timing gates. The test was repeated three times as fast as possible in the same direction, with one-minute rest between trials.

Balance

A modified Star Excursion Balance Test (SEBT) was used to measure single leg balance and proprioception using a composite score. Each participant completed the SEBT following the methodology as outlined in a previous study (30). Each participant was allowed seven trials for each direction. The first four trials were practice followed by three recorded trials (117). The participants' right lower limb measurement, from the most distal end of the anterior superior iliac spine to the centre of the malleolus, were taken and recorded for the composite score (30). The test was only performed on the right side for all participants due to time constraints. A SEBT composite score was calculated by dividing the maximum reach distance in the anterior (A), posterolateral (PL) and posteromedial (PM) directions by 3 times the limb length (LL) of the individual participant, then multiplied by 100 ((A + PL + PM)/(LL x 3) x100) (30).

Statistical analysis

Normality was tested using the Shapiro-Wilk test and by visual review of histogram graphs (SPSS, version 22). A spreadsheet for comparing the means of two groups (controlled trials, crossovers and time series) was used to log-transform the data prior to analysis and derive magnitude based qualitative inferences as to the true difference between groups (57). Within-session reliability of all test variables, other than prone hold which was a single maximal-effort test, were calculated through an online spreadsheet (60). Reliability was assessed using the interclass correlation coefficient (ICC) and typical error (TE) of measurement. To determine the magnitude of the ICC, threshold values were 0.1 (low), 0.3 (moderate), 0.5 (high), 0.7 (very high), 0.9 (nearly perfect), 1.0 (perfect) (59). The group comparisons included comparing year 9 grade one players to lower grade year 9 players and comparing players by position (circle vs non-circle) within grade one (year 9) and grade two (year 9 and year 10 combined). A Cohen's d effect size (ES) of 0.2 was used as the threshold for substantial differences (58). Inferences were based on the likelihood the true value of the ES was greater than 0.2 using the following scale: 25-75% possibly, >75% likely, >95% very likely, >99.5% most likely (58). Where the effect had a >5% probability of being substantially negative or substantially positive the inference was stated as unclear. Magnitudes of observed ES's were interpreted based on the following scale: 0.2-0.59 (small), 0.6-1.19 (moderate), 1.2-1.99 (large), 2.0-3.99 (very large), >4 (extremely large), and their inverse (58).

Results

Differences between playing grades

Within session reliability is presented in Table 5. Results, including raw outcomes and differences in performance between players from different grades can be seen in Table 6 and Table 7. Grade one players demonstrated greater jump ability than lower grade players with moderate (ES= 0.85) to large (ES= 1.37) differences in horizontal jump distance, and small (ES= 0.41) to moderate (ES= 0.61) differences in vertical jump height. Grade one players were also faster with moderate (15 m, ES= -0.68) to small (ES= -0.25 to -0.58) differences in sprint times, compared to grade two players. There were also moderate (ES= -0.69 and -0.75) differences in 20 m and 15 m sprint times between grade one and grade four players, while the differences in sprint times over shorter distances were unclear. Grade one players recorded faster times for the T-test with moderate (ES= -0.73) to large (ES= -1.31) differences. Grade one players also performed better on the TTS test (ES= -0.69) than grade four players, while other comparisons for TTS and all SEBT comparisons were unclear. There was a small difference (ES= 0.28) found in the prone hold between grade one and two players, and a moderate difference (ES= 1.17) between grade one and four players.

Table 5. Reliability statistics by grade and all groups for all test variables.

	Year 9 Grade one (*n*= 26)		Year 9 Grade two (*n*= 42)		Year 9 Grade four (*n*= 8)		Year 10 Grade two (*n*= 26)		All Groups (*n*= 102)	
Test Variable	**ICC (90% CI)**	**TE (90% CI)**	**ICC (90% CI)**	**TE (90% CI)**	**ICC (90% CI)**	**TE (90% CI)**	**ICC (90% CI)**	**TE (90% CI)**	**ICC (90% CI)**	**TE (90% CI)**
T-Test (s)	0.87 (0.78-0.93)	0.38 (0.32-0.46)	0.87 (0.81-0.92)	0.36 (0.32-0.43)	0.97 (0.91-0.99)	0.21 (0.16-0.36)	0.90 (0.84-0.95)	0.32 (0.27-0.40)	0.91 (0.88-0.94)	0.30 (0.27-0.33)
Sprint 20m (s)	0.69 (0.52-0.82)	0.57 (0.48-0.70)	0.59 (0.42-0.72)	0.65 (0.57-0.77)	0.80 (0.49-0.94)	0.52 (0.40-0.87)	0.60 (0.39-0.77)	0.64 (0.54-0.81)	0.65 (0.55-0.74)	0.60 (0.55-0.67)
Sprint 15m (s)	0.66 (0.48-0.80)	0.59 (0.50-0.73)	0.68 (0.54-0.79)	0.57 (0.50-0.68)	0.84 (0.59-0.95)	0.46 (0.36-0.77)	0.57 (0.34-0.74)	0.67 (0.56-0.84)	0.69 (0.59-0.77)	0.57 (0.51-0.63)
Sprint 10m (s)	0.58 (0.37-0.74)	0.66 (0.56-0.82)	0.56 (0.39-0.70)	0.67 (0.58-0.79)	0.80 (0.50-0.94)	0.52 (0.40-0.86)	0.42 (0.16-0.96)	0.77 (0.64-0.97)	0.57 (0.45-0.67)	0.66 (0.60-0.74)
Sprint 5m (s)	0.33 (0.09-0.56)	0.83 (0.70-1.02)	0.36 (0.16-0.54)	0.81 (0.70-0.95)	0.72 (0.36-0.91)	0.59 (0.46-0.99)	0.19 (-0.07-0.46)	0.90 (0.75-1.14)	0.36 (0.23-0.49)	0.80 (0.73-0.90)
Sprint 2m (s)	0.24 (0.74-1.08)	0.88 (0.74-1.08)	0.18 (-0.02-0.38)	0.91 (0.79-1.08)	0.65 (0.25-0.89)	0.65 (0.50-1.09)	0.14 (-0.13-0.41)	0.93 (0.78-1.17)	0.26 (0.13-0.40)	0.86 (0.78-0.97)
Vertical jump (cm)	0.92 (0.86-0.96)	0.29 (0.25-0.36)	0.89 (0.83-0.93)	0.34 (0.29-0.40)	0.74 (0.38-0.92)	0.58 (0.45-0.97)	0.85 (0.74-0.92)	0.40 (0.34-0.52)	0.74 (0.66-0.81)	0.51 (0.46-0.57)
Horizontal Jump (cm)	0.87 (0.79-0.93)	0.37 (0.31-0.45)	0.85 (0.75-0.91)	0.39 (0.34-0.46)	0.79 (0.49-0.94)	0.53 (0.41-0.88)	0.81 (0.69-0.89)	0.45 (0.38-0.56)	0.81 (0.81-0.90)	0.38 (0.34-0.42)
SEBT (composite score)-Anterior	0.79 (0.66-0.88)	0.47 (0.40-0.59)	0.82 (0.73-0.89)	0.43 (0.38-0.52)	0.77 (0.45-0.93)	0.55 (0.42-0.91)	0.90 (0.83-0.95)	0.30 (0.27-0.41)	0.82 (0.76-0.87)	0.43 (0.39-0.48)
SEBT (composite score)-Posterolateral	0.69 (0.51-0.82)	0.57 (0.49-0.72)	0.81 (0.71-0.88)	0.45 (0.39-0.53)	0.92 (0.78-0.98)	0.34 (0.26-0.57)	0.92 (0.86-0.96)	0.30 (0.25-0.37)	0.79 (0.72-0.95)	0.47 (0.42-0.52)
SEBT (composite score)-Posteromedial	0.81 (0.68-0.89)	0.45 (0.39-0.57)	0.82 (0.73-0.89)	0.43 (0.37-0.52)	0.81 (0.51-0.94)	0.51 (0.40-0.85)	0.90 (0.82-0.94)	0.33 (0.28-0.42)	0.84 (0.78-0.88)	0.41 (0.37-0.46)
TTS (ms)	0.41 (0.18-0.62)	0.78 (0.66-0.96)	0.23 (0.04-0.43)	0.88 (0.77-1.04)	0.16 (-0.27-0.64)	0.93 (0.70-1.50)	0.32 (0.08-0.55)	0.83 (0.71-1.04)	0.31 (0.17-0.45)	0.83 (0.76-0.94)

ICC=intraclass correlation coefficient; TE= typical error; CI= confidence interval; SEBT=star excursion balance test; TTS=time-to-stabilisation

Table 6. Physical performance characteristics of Grade one and Grade two female netball players.

Test Variable	Grade one (*n*= 26) mean ±SD	Grade two (*n*= 42) mean ±SD	Mean Difference: ES (90% CI)	ES Magnitude	Qualitative Inference
Prone Hold (s)	93.81 ±40.00	89.79 ±59.90	0.28 (-0.11 to 0.68)	small	possibly
T-Test (s)	13.34 ±0.79	13.99 ±0.94	-0.73 (-1.14 to -0.33)	moderate	very likely
Sprint 20m (s)	3.64 ±0.25	3.71 ±0.25	-0.25 (-0.66 to 0.17)	small	possibly
Sprint 15m (s)	3.11 ±0.16	3.22 ±0.16	-0.68 (-1.10 to -0.27)	moderate	very likely
Sprint 10m (s)	2.33 ±0.14	2.40 ±0.12	-0.58(-1.00 to -0.16)	small	likely
Sprint 5m (s)	1.46 ±0.10	1.51 ±0.10	-0.56 (-0.97 to -0.14)	small	likely
Sprint 2m (s)	0.82 ±0.08	0.86 ±0.08	-0.49 (-0.91 to -0.07)	small	likely
Vertical jump (cm)	40.01 ±7.77	36.75 ±6.82	0.41 (-0.01 to 0.83)	small	likely
Horizontal Jump (cm)	185.46 ±19.62	169.48 ±17.46	0.85 (0.43 to 1.26)	moderate	very likely
SEBT (composite score)	94.40 ±7.75	94.69 ±6.74	-0.05 (-0.47 to 0.37)	trivial	unclear
TTS (ms)	1026.40 ±279.30	1026.84 ±332.29	0.05 (-0.36 to 0.45)	trivial	unclear

ES= effect size; CI= confidence interval; SEBT=star excursion balance test; TTS=time-to-stabilisation; ES Magnitude: <0.2 (trivial), 0.2-0.59 (small), 0.6-1.19 (moderate), 1.2-1.99 (large), 2.0-3.99 (very large), >4 (extremely large), including their inverse. Qualitative Inference: Based on the likelihood of ES > 0.20 using the following scale 25-75% (possibly), >75% likely, >95% very likely

Table 7. Physical performance characteristics of Grade one and Grade four female netball players.

Test Variable	Grade one (*n*= 26) mean ±SD	Grade four (*n*= 8) mean ±SD	Mean Difference: ES (90% CI)	ES Magnitude	Qualitative Inference
Prone Hold (s)	93.81 ±40.00	52.75 ±25.78	1.17 (0.43 to 1.91)	moderate	very likely
T-Test (s)	13.34 ±0.79	14.85 ±1.27	-1.31 (-2.05 to -0.57)	large	very likely
Sprint 20m (s)	3.64 ±0.25	3.91 ±0.38	-0.69 (-1.45 to 0.06)	moderate	likely
Sprint 15m (s)	3.11 ±0.16	3.27 ±0.21	-0.75 (-1.47 to -0.03)	moderate	likely
Sprint 10m (s)	2.33 ±0.14	2.42 ±0.18	-0.46 (-1.19 to 0.27)	small	unclear
Sprint 5m (s)	1.46 ±0.10	1.49 ±0.14	-0.16 (-0.91 to 0.60)	trivial	unclear
Sprint 2m (s)	0.82 ±0.08	0.82 ±0.12	0.08 (-0.68 to 0.84)	trivial	unclear
Vertical jump (cm)	40.01 ±7.77	35.29 ±5.02	0.61 (0.01 to 1.22)	moderate	likely
Horizontal Jump (cm)	185.46 ±19.62	160.13 ±14.04	1.37 (0.73 to 2.02)	large	most likely
SEBT (composite score)	94.40 ±7.75	92.60 ±6.37	0.23 (-0.42 to 0.87)	small	unclear
TTS (ms)	1026.40 ±279.30	1306.50 ±424.44	-0.69 (-1.41 to 0.04)	moderate	likely

ES= effect size; CI= confidence interval; SEBT=star excursion balance test; TTS=time-to-stabilisation; ES Magnitude: <0.2 (trivial), 0.2-0.59 (small), 0.6-1.19 (moderate), 1.2-1.99 (large), 2.0-3.99 (very large), >4 (extremely large), including their inverse. Qualitative Inference: Based on the likelihood of ES > 0.20 using the following scale 25-75% (possibly), >75% likely, >95% very likely

Differences between playing positions

Performance measures, including raw outcomes and differences between playing positions are shown in Table 8 (Grade two) and Table 9 (Grade one). Grade two circle players jumped further than non-circle players (ES= -0.29). In contrast, grade two non-circle players demonstrated greater vertical jump heights than circle players (ES= 0.35). Additionally, grade two non-circle players were faster than circle players with small differences in 15 m (ES= -0.35), 10 m (ES= -0.33), 5 m (ES= -0.38) and 2 m (ES= -0.42) sprint times. Non-circle players demonstrated faster T-test times, with small differences found (ES= -0.55). Grade two non-circle players also performed better in both the SEBT (ES= 0.55) and the TTS (ES= -0.47). Grade two circle players were found to be taller than non-circle players, with a large difference (ES= 1.3) found in height between the positional groups. In grade one, the only clear difference was circle players ran faster than non-circle players over 20 m (ES= 0.75). All other differences in physical performance measures between playing positions were unclear.

Table 8. Physical performance characteristics of positions in Grade two.

Test Variable	Circle (*n*= 36) mean ±SD	Non-circle (*n*= 32) mean ±SD	Mean Difference: ES (90% CI)	ES Magnitude	Qualitative Inference
Prone Hold (s)	83.19 ±44.46	90.03 ±58.32	0.12 (-0.28 to 0.52)	trivial	unclear
T-Test (s)	14.58 ±1.43	13.91 ±1.00	-0.55 (-0.95 to -0.16)	small	likely
Sprint 20m (s)	3.69 ±0.30	3.64 ±0.19	-0.14 (-0.54 to 0.25)	trivial	unclear
Sprint 15m (s)	3.27 ±0.18	3.21 ±0.13	-0.35 (-0.75 to 0.05)	small	possibly
Sprint 10m (s)	2.44 ±0.15	2.40 ±0.09	-0.33 (-0.73 to 0.06)	small	possibly
Sprint 5m (s)	1.54 ±0.10	1.50 ±0.07	-0.38 (-0.78 to 0.02)	small	likely
Sprint 2m (s)	0.88 ±0.70	0.85 ±0.07	-0.42 (-0.82 to -0.01)	small	likely
Vertical jump (cm)	35.78 ±7.33	37.61 ±5.26	0.35 (-0.05 to 0.74)	small	possibly
Horizontal Jump (cm)	170.87 ±17.53	165.91 ±15.39	-0.29 (-0.69 to 0.11)	small	possibly
SEBT (composite score)	91.47 ±6.34	95.06 ±6.63	0.55 (0.15 to 0.95)	small	likely
TTS (ms)	1125.12 ±349.51	976.17 ±342.79	-0.47 (-0.87 to -0.07)	small	likely

ES= effect size; CI= confidence interval; SEBT=star excursion balance test; TTS=time-to-stabilisation; ES Magnitude: <0.2 (trivial), 0.2-0.59 (small), 0.6-1.19 (moderate), 1.2-1.99 (large), 2.0-3.99 (very large), >4 (extremely large), including their inverse. Qualitative Inference: Based on the likelihood of ES > 0.20 using the following scale 25-75% (possibly), >75% likely, >95% very likely

Table 9. Physical performance characteristics of positions in Grade one.

Test Variable	Circle (*n*= 12) mean ±SD	Non-circle (*n*= 14) mean ±SD	Mean Difference: ES (90% CI)	ES Magnitude	Qualitative Inference
Prone Hold (s)	87.17 ±40.13	99.50 ±40.48	0.35 (-0.30 to 1.01)	small	unclear
T-Test (s)	13.40 ±0.74	13.31 ±0.85	-0.12 (-0.77 to 0.53)	trivial	unclear
Sprint 20m (s)	3.55 ±0.23	3.73 ±0.24	0.75 (0.09 to 1.40)	moderate	likely
Sprint 15m (s)	3.10 ±0.19	3.12 ±0.14	0.08 (-0.58 to 0.74)	trivial	unclear
Sprint 10m (s)	2.33 ±0.17	2.33 ±0.11	-0.02 (-0.68 to 0.65)	trivial	unclear
Sprint 5m (s)	1.46 ±0.12	1.46 ±0.09	-0.05 (-0.71 t 0.61)	trivial	unclear
Sprint 2m (s)	0.82 ±0.09	0.82 ±0.08	-0.03 (-0.68 to 0.63)	trivial	unclear
Vertical jump (cm)	40.15 ±7.25	39.89 ±8.46	-0.07 (-0.72 to 0.57)	trivial	unclear
Horizontal Jump (cm)	184.67 ±15.35	186.14 ±23.24	0.03 (-0.61 to 0.68)	trivial	unclear
SEBT (composite score)	95.21 ±9.32	93.71 ±6.40	-0.16 (-0.82 to 0.50)	small	unclear
TTS (ms)	1020.89 ±289.73	1031.12 ±280.96	0.03 (-0.62 to 0.68)	trivial	unclear

ES= effect size; CI= confidence interval; SEBT=star excursion balance test; TTS=time-to-stabilisation; ES Magnitude: <0.2 (trivial), 0.2-0.59 (small), 0.6-1.19 (moderate), 1.2-1.99 (large), 2.0-3.99 (very large), >4 (extremely large), including their inverse. Qualitative Inference: Based on the likelihood of ES > 0.20 using the following scale 25-75% (possibly), >75% likely, >95% very likely

Discussion

The results of this study showed differences in the physical performance capabilities between NZ secondary school netball players in different grades. There were also differences found between playing positions within grades, providing information that could assist with position-specific coaching.

The biggest differences in physical performance measures were found when comparing grade one with grade two and four players in this study (Table 6 and Table 7, respectively). Grade one players were found to physically outperform those in lower grades in most of the physical performance measures. Grade one players were found to jump further and higher, run faster, have greater core endurance and faster change of direction speed. As teams had been pre-allocated to grades based on playing ability prior to the study, it could be expected that grade one players physically excelled in most tests to meet the physical requirements of netball at a higher level. The physical demands during a game of netball include acceleration and short sprints (forward, back and sideways), change of direction speed, side-shuffling, jumping and landing, and balance (36). Therefore, as expected, the players identified as more talented by coaches performed these physical capabilities to a higher standard.

It has been suggested that longitudinal investigations of physiological characteristics can provide important information to coaches and sports scientists through physiological profiling of athletes (141). A study evaluating height, body mass and physical performance measures of English regional academy netball players found that all measures improved across age categories from under 15 to under 19 years (141). Athletes in the under 19 age group displayed significantly faster 5 m sprint and change of direction speed times. They also jumped significantly higher than the under 15 age group (141). These findings were similar to the current study; however, groups in this study were only separated by playing level and not age. The reliability of the measures used in this study were also slightly lower than the study investigating academy netball players (Table 5). This could be due to the difference in athletic ability between academy and secondary school athletes. Additionally, the academy players were familiar with tests performed in the previous study as they were part of their normal training and monitoring routine (141), whereas the secondary school athletes in the current study were not familiar with the tests used. Both studies provide preliminary reference data to aid in athlete development with the prescription of appropriate training programs. The inclusion of age group comparisons in future studies could be important for long-term athlete development.

Previous studies in other team sports have also reported that higher ranked players physically outperform their lower ranked peers (40, 78). Manson and colleagues (2014) found that starting players were stronger in the lower body, were faster, and had a greater VO_2max compared to non-starting players in female football, providing recommendations for greater specificity in training and group selection. Similar findings have also been reported in junior elite and sub-elite rugby league players (40). Junior elite players were found to have better speed, change of direction speed, vertical jump height, and estimated maximal aerobic power, compared to sub-elite players. Additionally, differences in physical performance measures between junior volleyball players competing at the elite, semi-elite, and novice levels have also been reported, providing a performance profile and physical performance standards for this sport and age group (38). Studies investigating the physiological characteristics of rugby league and netball players at different playing levels also provided a performance profile and physical performance standards at each level of the sport (41, 126). However, comparisons were made between groups in these studies that were very different in playing ability (i.e. from professional/elite to under 19, 17 and 13 age groups) and therefore differences could be expected.

Results of this study provide a performance profile which coaches may use to assist with talent identification of youth netball players. Moderate to very large associations between relative isometric strength, vertical jump performance and sprint and change of direction speed have been found in academy netball players (140). Players considered as 'stronger' had the ability to produce significantly greater vertical jump height and faster sprint and change of direction times, compared to 'weaker' players (140). Therefore, findings suggest that maximum strength is an important aspect of physical preparation for youth netball players, and success in the sport is highly dependent on such physical characteristics (139, 140). In addition to utilising physical performance measures in talent identification, it has been reported that sport-specific skill acquisition (e.g. pattern recall, decision making, and anticipation) discriminates between expert and novice athletes (42). Performance measures could be masked if younger athletes are competing in a higher age category if their skill level is considered superior to their peers (141). A study involving junior (mean age 15.5 ±1.0 years) volleyball players, involving both male and female athletes, found no differences between selected and non-selected players for any of the physiological or anthropometric variables measured (39). It was suggested that skills were more important in identifying talented junior volleyball players (39). However, in comparison to this study, these findings were reported in different population groups, involved professional or older players and different sports, and we did not measure technical or tactical skill components of netball.

Physical demands of the seven playing positions in netball have been investigated in youth to elite level netball with differences found between positions (6, 17, 22, 35, 36, 142). Differences in physical attributes between positions in netball could be due to the court spatial constraints imposed by the rules of the game (137, 141). These constraints have been reported to influence active time during a game of netball (36) and this could affect the development of physical capabilities. Player load was found to be similar between WA and WD, and GA and GD positions, highlighting the connection between physical demands and court constraints (17, 137). Previous studies analysing positional differences in netball have investigated individual positions comparing defensive (GK, GD, WD) versus attacking players (C, WA, GA, GS) (6, 17, 35, 36) or the differences between three positions (C, GS, GK) (22). A commonality between all studies was the greatest player load and highest amount of activity found in the C position and the lowest player load and least amount of activity found in the GS position (6, 17, 22, 35, 36, 137).

When comparing physical performance and anthropometric measures in youth netball, we found differences between playing positions (Table 8 and Table 9). Non-circle players had lower straight-line sprint and change of direction times. Positions which have been found to have the greatest running and change of direction load are those with the least court constraints, therefore this could explain why the non-circle players were found to be faster at change of direction and faster over short distances. Circle players work predominantly in one third of the court only, suggesting the need to meet lower physical demands of game-play (17). Fox et al. (2013) found mid-court positions (GD, WD, C, WA, GA) performed jogging, running and sprinting more frequently. As non-circle players are moving through the court at greater speeds, they also need to be able to stop quickly and safely which could be shown by their ability to perform better during the static and dynamic balance assessments. They also need to be able to have stability when feeding and defending the ball on the edge of the shooting circle. Balance assists many movements in netball (e.g. jump and land, passing and guarding the ball) and is an important physical measure to test (113). We chose to focus on positional differences based on court area restrictions which, as shown by previous research, appear to have the most influence on physical demands. Therefore, positional groups in this study were divided into circle (GK, GS, GA, GD) and non-circle (C, WA, WD) players.

It might be expected that positions under the goal need to have a higher vertical jump for rebounds and to receive/defend high balls into the circle. However, similar to other studies (6, 17, 142), we found that non-circle players tend to have a higher vertical jump. Centre players have been found to demonstrate significantly greater jump heights compared to defending players with a trend for increased jump height compared to shooters (142). Additionally, the GS position has been found to perform far fewer jumps than all other positions (36). It may be that, as circle players were taller than non-circle players in this study (mean difference= 6.47 cm), they rely on their height to reach or receive the ball without the need to jump. Additionally, previous findings have shown that the C position had a high vertical player load, suggesting non-circle players have a greater vertical load and thus vertical jump ability (17). However, it has also been found that the C position has the highest forward player load (17) and better performance in single leg forward hops (142), contradicting our findings which showed circle players were better at horizontal jump performance. This may be due to the difference in the level of netball players analysed in each study.

Generally, non-circle players were physically better across the board in the physical performance tests in the current study (Table 8 and Table 9). As players are still developing in this age group, it may be that the more physically able tend to take non-circle positions, and other players get ‘stuck under the goal’ due to their height. It has previously been found that height was greater in defenders compared to centres of netball players of a similar age group (142). Positional demands of netball likely explain the differences in height, where tallness could be viewed as a desirable characteristic for shooters and defence players (142). This has been suggested by Gil et al. (2007) as occasionally occurring in youth soccer. At times, heavier and bigger athletes are selected as goalkeepers, not based on their skill for this position but rather, because they are not as fit as other players in their team to play other positions. This could be a caution to coaches of this developmental age-group. If taller players do not learn how to move effectively (e.g. jump vertically instead of relying on their height), especially at this age group level, it could impact their future game development, skills and play.

Limitations

There were some limitations to this study. Firstly, there were no skills-based variables measured in this study. As game-specific skill qualities have been shown to be an important aspect of talent identification and team selection, it should be considered for future studies. Other qualities that may assist with talent identification include attitude, mental resilience and coordination (42). Secondly, a common discriminating variable that has been shown to determine starters and non-starters was a high VO_2max output (40). As we did not measure VO_2max we were unable to compare this measure. Therefore, field-based assessments of aerobic capacity, such as the Yo-yo Intermittent Recovery Test or Beep Test, could be included in future research in NZ secondary school netball players. Furthermore, all tests in the current study involved a range of field-based tests. Further research is needed to examine power and lower body strength characteristics of NZ netball players of this age group. Additionally, although this study involves a cross-sectional analysis of participants from the same chronological age group, caution must be taken for the interpretation of the results as growth and maturation status were not recorded. As the maturational process is unique to each individual, this should be considered in future research involving this age group. The low sample size in some groups, particularly the small number of netball players in the Grade four group, is another limitation of this study.

Conclusion

In conclusion, the present study found physical performance and anthropometric differences between netball players of different playing grades and between playing positions. These findings add to the growing body of literature and information for talent identification and training in youth netball. Netball coaches and strength and conditioning coaches could use the findings from this study to train position-specific demands. Position-specific training is important for developing the capabilities needed for game-play, therefore a greater awareness of this is needed when designing sport-specific skill-based training programs. It could also help to identify players for certain positions based on their physical performance skills. A program incorporating speed, change of direction ability and plyometrics should be used for non-circle positions, with the inclusion of developing horizontal force direction for circle positions. Furthermore, future studies should also consider including a skills-based test, as well as other predictors (e.g. attitude, mental toughness, physiological) that may influence talent identification and team selection in this age group.

Section 2: Effectiveness of the NetballSmart Dynamic Warm-up

Chapter 4: The Effect of the NetballSmart Dynamic Warm-up on Physical Performance in Youth Netball Players

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

Reference:

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.

Overview

The purpose of this study was to investigate the efficacy of the NetballSmart Dynamic Warm-up in improving physical performance measures in youth netball players. The study used a cluster randomised controlled trial approach with a seven-week intervention in secondary school netball. A total of 81 youth netball players (Intervention group, *n*= 45; Control group, *n*= 36) participated in the study. Performance measures included prone hold, change of direction, sprint, vertical and horizontal jump, Y-balance and time-to-stabilisation. Mixed effects models and t-tests were used to determine significant differences of pre and post measures between groups. Significant improvements in prone hold (β= 20.46 s; p= 0.01) and vertical jump (β= 6.73 cm; p= 0.01) were found in the intervention group compared to the control group; while horizontal jump was found to significantly decrease (β= -9.86 cm; p= 0.03) in comparison to the control group. The results of this study show the NetballSmart Dynamic Warm-up can improve some physical performance measures in youth netball players. It is recommended that coaches should consider implementing the warm-up in their netball programmes.

Introduction

Netball is a team sport that is common amongst women within the commonwealth countries (130). Despite being considered a “non-contact” sport, netball is a physically demanding game that requires a high level of fitness, strength, speed, power and agility (84, 134). It requires the performance of explosive anaerobic movements (repeated jumping, turning, sprinting, cutting, acceleration and deceleration); all while catching and passing a ball (139). Because of the demands placed on the body during a game, there is a high risk of injury to the lower body, in particular the ankle (most common) and knee (most expensive and often most severe) (84, 134). As netball is the leading women’s sport in New Zealand (NZ) with approximately 145,000 affiliated players and is the number one sport in secondary schools (92), the number of injuries is high. Therefore, in 2016 Netball New Zealand (NNZ), in conjunction with the Accident Compensation Corporation (ACC), introduced a modified "FIFA 11+" warm-up known as the NetballSmart Dynamic Warm-up (NDW) to help reduce these injuries.

Many neuromuscular warm-up programmes have been shown to help reduce injury risk in various sports (25, 67, 76, 100, 128). A recent systematic review focused on youth concluded there was good evidence a neuromuscular warm-up was effective for reducing injury risk (27). The most investigated warm-up programme is the FIFA 11+, a full body warm-up designed in football by an international group of experts to reduce injuries in football players (9, 128). Research has demonstrated the effectiveness of this programme in both men and women, reporting 30 to 50% fewer injuries in players who performed the programme at least twice a week (28, 76, 104, 124). The majority of the exercises included in the FIFA 11+ are common exercises; however, they are not routinely used in football training programmes (28). Thus, in addition to warming the body up in preparation for training and games, adding these exercises into a warm-up programme that can become part of a football training routine should lead to strengthening of the lower body and core muscles, improvements in static, dynamic and reactive neuromuscular control, coordination, balance, agility and jump techniques (28). A key element of the programme is using correct technique and proper movement, particularly correct posture and body control and alignment (28). The NDW is based on the structure and exercises performed in the FIFA 11+, however slight modifications have been made to the programme to make it more sport-specific to netball (93). The order of the exercises has been changed and additional "high knees" and "butt kicks" exercises are included in the NDW, as well as various jump and land exercises. Like Part 2 (strength, plyometrics and balance) of the FIFA 11+, exercises in Part A (strength) and C (dynamic preparation) of the NDW have three levels of increasing difficulty. The final section of the NDW (Part D) involves netball specific preparation. In this section, instead of running and bounding across a football pitch (Part 3, FIFA 11+), the warm-up involves running (75-80% of maximum speed) and stopping at 3 m intervals, planting and cutting and a single leg plyometric exercise with single leg balance ("prop, prop and stick"). The complete warm-up is performed prior to trainings and games, however before games Part A is not included (93). For more details see the manual on the official NNZ website (https://www.netballnz.co.nz/Downloads/Assets/41254/1/NetballSmart%20Dynamic%20Warm-up:%20Booklet.pdf).

In addition to reducing injuries, neuromuscular warm-up programmes may also improve physical performance. When injury prevention programmes are regularly implemented into team trainings through warm-up it could be expected that physical performance will improve. There is existing evidence that warm-up-based injury prevention programmes (such as the FIFA 11+) can have a positive effect on selected performance measures in some sports (football, futsal and basketball) (4, 66, 114, 154). However, several other studies have not reported improvements (72, 131, 148). Furthermore, there has been no research evaluating the effect of the NDW warm-up programme on physical performance in netball. Although the main purpose for the NDW is to prevent injuries, knowing the training effect (e.g. changes in strength and balance (3, 87, 101, 108)) caused by this warm-up programme could help in identifying the potential mechanisms behind the reduction in injury incidence as well as whether players may have additional performance benefits.

Evidence the NDW improves performance may also improve uptake and adherence to the programme if coaches are convinced there is a performance aspect to the warm-up (27). The importance of greater adherence to a neuromuscular warm-up has been reported previously as a critical point for successful implementation (129, 132). Higher adherence to the FIFA 11+ significantly improved functional balance and reduced injury risk (132). Therefore, the purpose of this study was to determine if the NDW could improve physical performance measures in youth netballers.

Methods

Participants

Initially, 137 participants were recruited to participate in this study. In total, 81 participants from 14 teams (five different schools) completed both pre-and post-testing and were included in the analysis (See Figure 3 for flow of participants). Participants were allocated to an intervention (INT: *n*= 45, age 13.33 ±0.48 years; height 165.41 ±6.11 cm; weight 56.97 ±10.16 kg) or control (CON: *n*= 36, age 13.25 ±0.50 years; height 168.76 ±4.25 cm; weight 64.50 ±10.11 kg) group. Participants were recruited through local secondary schools and a cluster randomised controlled design was used to minimise contamination bias within teams. Therefore, all players from one team were assigned to the same warm-up intervention. All participants were healthy and free from injury in the last six months and were training and competing in a secondary school netball programme at the time of data collection. All teams were involved in netball-specific training twice a week with one competitive game (duration the same for all participants). The participants had no previous resistance or neuromuscular training background. Prior to participation, all participants and guardians were fully informed of the experimental procedures before giving their informed consent and assent. This study was approved by the University Ethics Committee.

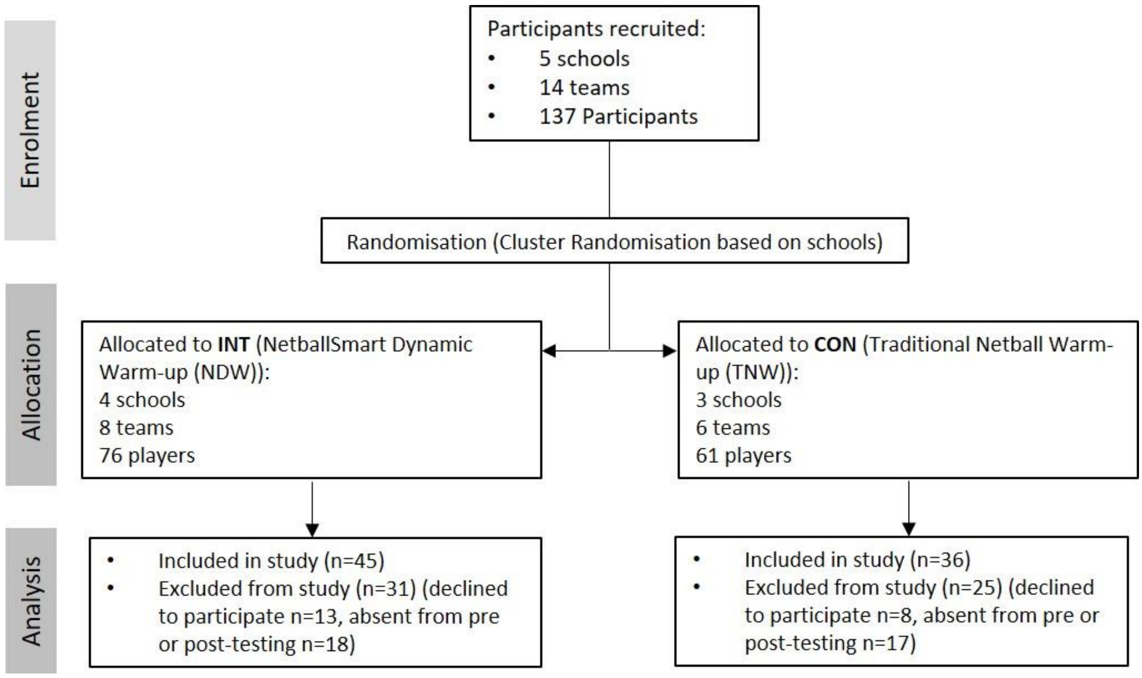

Figure 3. Flow of participants through the study

Intervention

The INT followed the NDW for seven weeks (3x per week), while the CON followed a ‘traditional’ netball warm-up (TNW). The NDW was delivered to the INT by a qualified trainer 2x per week before training, and 1x per week by the team coach before games. The TNW consisted of jogging, dynamic movement and sprints and was delivered by the team coach. Both programmes took approximately 15-20 minutes to complete per session.

Testing procedures

All testing was conducted during the early competitive phase of the netball season on-site at participating secondary schools. The tests included the Y-balance, 2-20 m straight line sprint (split sprint times), T-test (change of direction speed), jump performance (vertical and horizontal jump), prone hold, and time-to-stabilisation (TTS). All test protocols selected for this study have been used in previous research (65, 66, 79, 125). All testing was performed by the same person each time and standardised instructions and protocols were used for each test. These tests have been reported to show moderate to high within-session reliability (Intraclass correlation coefficient= 0.3-0.91) in a similar group of youth netball players (81). Participants performed a 10-minute standardised warm-up that replicated a generic netball warm-up. After warm-up and test familiarisation three recorded trials were performed at each test (with up to one-minute rest between trials). The mean of these three trials was used for analysis.

Horizontal jump

Participants started with their feet flat on the ground and toes behind a line marked perpendicular to a measuring tape (0 cm mark). They then 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 (79). 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.

Vertical jump

An AMTI portable force plate (Advanced Mechanical Technology, Inc. Watertown, MA) was used to measure vertical jump height (400 Hz sampling rate). Participants stood in the centre of the force plate, feet hip width apart and hands on their hips. They then performed a maximal countermovement jump (CMJ) keeping their lower limbs extended during the flight phase of a jump (65). A custom-made LabVIEW programme (National Instruments, 2014, Auckland, NZ) determined jump height by finding total flight time and using the following equation: jump height (cm) = $1/2\ g\ (t/2)^2$, where g = 9.81 m sec^{-2} and t = time in air (85).

Time-to-stabilisation

To measure TTS, participants were first assessed for maximal vertical jump height (bilateral) using a Vertec (Swift Performance Equipment, Queensland, AUS) which was set above the centre point of an AMTI portable force plate (Advanced Mechanical Technology, Inc. Watertown, MA). Once maximum jump height was established, the Vertec was set at 50% of this value creating an individual target to control for jump height during each TTS test (65). To begin the TTS test, participants stood behind a marked line 20 cm from the centre of the force plate. Then, jumping from two feet, they performed a CMJ reaching for their individual jump height target. They were required to land on their right foot (single-leg) with their hands on their hips. The participant had to stabilise and adopt this balanced landing position as quickly as possible without any additional movement (i.e. hopping, swaying or letting the left foot touch the force plate) (65). They were required to hold this position for 10 seconds. The test was repeated if a participant fell or lost balance until three successful jumps were recorded. A custom-made LabVIEW programme (National Instruments, 2014, Auckland, NZ) was used to determine the time to stabilisation (ms) from the time of initial contact upon landing until stabilisation was within 5% of body mass (144) .

Prone hold

Participants were required to maintain a prone hold position (elbows on the ground, hands grasped, feet approximately hip width apart, head facing towards the ground and body straight from shoulder to heels) with no arching or bowing in the lower back for as long as possible (66). The test ended if the participant could not stay in the position any longer or if they excessively arched or bowed their lower back (at the discretion of the researcher). The maximum time (s) the participant maintained a correct position was recorded. This test was performed once.

Speed

Split sprint times (s) (2, 5, 10, 15 and 20 m) were measured with a Radar Gun (Stalker ATS II, Applied Concepts Inc., Richardson, TX) (125). Participants started from a still, split stance position 2 m directly in front of the radar gun. They were encouraged to sprint 20 m as fast as possible for three recorded trials. All files were analysed in a custom-made LabVIEW programme (National Instruments, 2014, Auckland, NZ) to find split times at each distance.

Change of direction

A T-test was used to measure change of direction ability (s) (65). Cones were set up on a netball court to resemble a ‘T’ shape with timing gates (Swift Performance Equipment, Queensland, AUS) placed at the start/finish line. The T-test was performed as follows: forward sprint (5 m) through the timing gates to the top of the “T”; side-shuffle to the left (5 m) cone, then to the right cone (10 m), and left again back to the centre cone (5 m); backpedal through the timing gates.

Balance

A Y-balance test (modified star excursion balance test) was used to measure right single leg balance using a composite score (30, 65). A total of 7 trials was allowed for each direction. The first four trials were practice followed by three recorded trials (117). The participants’ right lower limb measurement from the most distal end of the anterior superior iliac spine to the centre of the medial malleolus were taken and recorded for the composite score (30). A Y-balance composite score was calculated by dividing the maximum reach distance in the anterior (A), posterolateral (PL) and posteromedial (PM) directions by three times the limb length (LL) of the individual participant, then multiplied by 100 ((A + PL + PM)/(LL x 3) x100) (30).

Statistical analysis

Normality was tested using the Shapiro-Wilk test and by visual review of histograms. Paired t-tests were used to determine pre-post differences in all performance measures for the intervention and control 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: 0.2-0.59 (small), 0.6-1.19 (moderate), 1.2-1.99 (large), 2.0-3.99 (very large), >4 (extremely large) (58). Linear and generalised linear mixed effects models were developed to evaluate the effects between intervention and control groups. This approach was used to account for the cluster design using multiple sites (schools) and repeated measures (random effects). A robust standard error was applied to account for potential contamination between sites (two schools had both INT and CON groups). All models controlled for baseline measures. 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. 25; IBM Corporation, Chicago, IL) and Stata (College Park, TX) were used to perform the analyses.

Results

In the intervention group there were significant improvements in prone hold (ES= 0.48, p= 0.004), vertical jump (ES= 0.53, p= 0.001), and Y-balance (ES= 0.34, p= 0.003) (Table 10). In contrast there was reduced performance in 20 m sprint (ES= 0.42, p= 0.001). The significant changes found in the control group were improvements in Y-balance (ES= 0.64, p= 0.003) and 10-15 m sprint times (ES= -0.64, p= 0.01 and ES= -0.49, p= 0.01, respectively) (Table 11).

Table 10. **Mean pre-post differences in the intervention group (*n*= 45).**

Variable	Pre Test Mean ±SD	Post Test Mean ±SD	Difference Mean + 95% CI	ES Hedge's g + 95% CI	P value
Prone Hold (s)	82.93 ±50.65	105.04 ±40.73	22.11 (7.49 to 36.73)	0.48 (0.06 to 0.90)	0.004*
T-Test (s)	13.69 ±1.01	13.74 ±1.11	0.06 (-0.13 to 0.24)	0.05 (-0.37 to 0.46)	0.54
Speed Vmax	6.42 ±0.50	6.39 ±0.40	-0.04 (-0.13 to 0.06)	-0.07 (-0.48 to 0.35)	0.44
Sprint 20m (s)	3.79 ±0.29	3.91 ±0.28	0.12 (0.05 to 0.19)	0.42 (0.01 to 0.83)	0.001*
Sprint 15m (s)	3.27 ±0.19	3.25 ±0.16	-0.03 (-0.07 to 0.02)	-0.11 (-0.53 to 0.30)	0.21
Sprint 10m (s)	2.45 ±0.14	2.42 ±0.13	-0.03 (-0.07 to 0.01)	-0.22 (-0.63 to 0.19)	0.09
Sprint 5m (s)	1.55 ± 0.10	1.54 ±0.09	-0.01 (-0.04 to 0.02)	-0.10 (-0.52 to 0.31)	0.62
Sprint 2m (s)	0.89 ±0.08	0.90 ±0.07	0.02 (-0.01 to 0.04)	0.13 (-0.28 to 0.55)	0.17
Vertical Jump (cm)	30.60 ±8.96	34.74 ±6.47	4.13 (1.71 to 6.55)	0.53 (0.10 to 0.95)	0.001*
Horizontal Jump (cm)	161.91 ±15.56	157.76 ±17.75	-4.21 (-8.39 to -0.03)	-0.25 (-0.66 to 0.16)	0.05
Y-Balance Test (score)	90.82 ±5.73	93.17 ±7.71	2.36 (0.83 to 3.89)	0.34 (-0.07 to 0.76)	0.003*
TTS (ms)	1426.81 ±404.64	1533.45 ±364.35	106.65 (-6.25 to 219.54)	0.27 (-0.14 to 0.69)	0.06

Values are mean ±SD; ES=effect size; CI=confidence interval; * Significantly different pre-post ($p<0.05$)

Table 11. **Mean pre-post differences in the control group (*n*= 36).**

Variable	Pre Test Mean ±SD	Post Test Mean ±SD	Difference Mean + 95% CI	ES Hedge's g + 95% CI	P value
Prone Hold (s)	90.81 ±47.82	88.17 ±42.77	-2.64 (-15.43 to 10.15)	-0.06 (-0.52 to 0.40)	0.68
T-Test (s)	13.61 ±1.12	13.64 ±0.96	0.03 (-0.12 to 0.17)	0.03 (-0.43 to 0.49)	0.69
Speed Vmax	6.72 ±0.64	6.73 ±0.68	0.01 (-0.18 to 0.19)	0.01 (-0.45 to 0.48)	0.96
Sprint 20m (s)	3.88 ±0.17	3.83 ±0.24	-0.05 (-0.13 to 0.03)	-0.24 (-0.70 to 0.23)	0.22
Sprint 15m (s)	3.31 ±0.18	3.22 ±0.18	-0.09 (-0.16 to -0.03)	-0.49 (-0.96 to -0.03)	0.01*
Sprint 10m (s)	2.50 ±0.14	2.41 ±0.14	-0.08 (-0.14 to -0.02)	-0.64 (-1.11 to -0.16)	0.01*
Sprint 5m (s)	1.60 ±0.10	1.55 ±0.12	-0.05 (-0.10 to 0.01)	-0.45 (-0.92 to 0.02)	0.06
Sprint 2m (s)	0.95 ±0.09	0.91 ±0.10	-0.04 (-0.09 to 0.01)	-0.42 (-0.88 to 0.05)	0.09
Vertical Jump (cm)	37.15 ±7.95	35.65 ±7.16	-1.49 (-3.01 to 0.02)	-0.20 (-0.66 to 0.27)	0.05
Horizontal Jump (cm)	173.46 ±19.65	174.29 ±15.83	0.83 (-3.08 to 4.74)	0.05 (-0.42 to 0.51)	0.67
Y-Balance Test (score)	90.74 ±6.07	94.30 ±4.97	3.57 (1.72 to 5.41)	0.63 (0.16 to 1.11)	0.003*
TTS (ms)	1392.35 ±357.30	1540.92 ±414.49	148.58 (-24.29 to 321.45)	0.38 (-0.09 to 0.85)	0.09

Values are mean ±SD; ES=effect size; CI=confidence interval; * Significantly different pre-post ($p<0.05$)

Table 12. Outcomes of the mixed model comparing the effect in the intervention to the control group.

Univariate Models	Variable	β+ 95% CI	Robust Std. error	z	P value
1	Prone Hold (s)	20.46 (11.33 to 29.60)	4.66	4.39	0.001*
2	T-Test (s)	0.04 (-0.22 to 0.29)	0.13	0.28	0.78
3	Sprint 20m (s)	0.17 (-0.09 to 0.44)	0.14	1.26	0.21
4	Sprint 15m (s)	0.03 (-0.04 to 0.10)	0.04	0.72	0.47
5	Sprint 10m (s)	-0.01 (-0.06 to 0.03)	0.02	-0.63	0.53
6	Sprint 5m (s)	-0.01 (-0.05 to 0.03)	0.02	-0.61	0.54
7	Sprint 2m (s)	0.003 (-0.06 to 0.07)	0.03	0.09	0.93
8	Vertical Jump (cm)	6.73 (1.91 to 11.55)	2.46	2.74	0.01*
9	Horizontal Jump (cm)	-9.86 (-18.52 to -1.19)	4.42	-2.23	0.03*
10	Y-Balance Test (score)	-0.64 (-5.38 to 4.11)	2.42	-0.26	0.79
11	TTS (ms)	22.91 (-216.96 to 262.77)	122.38	0.19	0.85

* Significantly different between groups (p<0.05); Coefficient estimates the average difference in the effect between the 2 groups

The results of the mixed effects model revealed there were some significant differences between the intervention and control groups (Table 12). Prone hold time and vertical jump height improved by an estimated 20.46 s (p= 0.001) and 6.73 cm (p= 0.01) more on average respectively in the intervention group than in the control group. Horizontal jump distance was found to decrease on average by an estimated 9.86 cm in the intervention group in comparison to the control group (p= 0.03). No other significant differences between groups were found.

Discussion

The NetballSmart Dynamic Warm-up (NDW) was developed to help prevent injury and enhance performance at all age groups and levels of netball. There have been no previous studies reporting on the efficacy of this warm-up in youth netball players. Therefore, the present study investigated the effect of the NDW on performance measures in NZ secondary school netball players. Differences were found following the warm-up intervention, suggesting that the NDW could improve some physical performance measures. These results are comparable to previous literature showing that the FIFA 11+, or similar neuromuscular warm-up programmes designed to prevent injuries, can have a positive effect on performance (4, 66, 114, 120).

The main findings of this study were the significant improvements in prone hold and vertical jump in the intervention group compared to the control group (Table 12). In accordance with this, the biggest improvements in the intervention group were also in both prone hold (ES= 0.48) and vertical jump (ES= 0.53) (Table 10). Similar improvements in prone hold and vertical jump have been found in previous research implementing similar warm-up programmes (10, 65, 66, 114, 157). Prone hold performance was found to significantly improve in youth futsal players after performing the FIFA 11+ twice per week for four weeks (157) and in a group of youth male football players performing the FIFA 11 five days per week for six weeks (66). Core stability was also found to maintain or improve in a group of amateur male football players after performing the FIFA 11+ three times a week for nine weeks (65). The implementation of core stability exercises in injury prevention is based on the theory that dysfunction in core musculature contributes to musculoskeletal injury (64). Therefore, even though the ideal components of an injury prevention programme have not been determined (64), most multifaceted injury prevention programmes incorporate exercises that target neuromuscular control of the core through strength, endurance or balance and posture (66, 72, 120, 128, 148). According to Leetun et al. (2004), core stability is the product of motor control and muscular capacity of the lumbo-pelvic-hip complex, and muscular capacity refers to the athlete’s ability to generate or maintain force (endurance) in the lumbo-pelvic-hip complex. Improving core stability should be considered important for the prescription of all sports training programmes as sports activities are frequently performed in unstable positions (153), though there is little evidence showing how improvements in core stability can directly enhance sports performance (55, 112). In comparison, core stability has been shown to be important in injury prevention (69). Basketball and track athletes who experienced an injury over a season scored lower in core stability measures compared to those who did not get injured. Therefore, an improvement in prone hold performance (muscular endurance of the lumbo-pelvic-hip complex) may reduce the risk of injury.

Vertical jumping is a component in both the FIFA 11+ and the NDW (93, 128). The improvements we found in vertical jump have not been consistently found previously. Some studies have reported improvement in vertical jump performance after the implementation of a neuromuscular warm-up (10, 66, 154), but a number of studies have shown no significant or meaningful change (65, 72, 131, 148). Studies reporting improvements in vertical jump height have involved either football or futsal male athletes of various ages. A significant improvement of 6% was found in CMJ after performing the FIFA 11 for six weeks in youth male football players (66) and better jump height (7-10%) has also been reported in male football and futsal players of a slightly older adolescent age group after following the FIFA 11+ (114, 154). Furthermore, with the implementation of the FIFA 11+, Bizzini et al. (2013) reported significant improvements in CMJ (5.5%) in male football players (25.5 ±5.1 years). In contrast there were no improvements in CMJ in adolescent women’s football players following the FIFA 11+ or an alternate neuromuscular warm-up programme (72, 131). Due to the nature of the game, vertical jumping is a frequent movement performed in netball (36) and this could partly explain the greater improvement (4.13 cm; 13.5%) in jump height we observed in comparison to previous football studies. Due to the game demands of netball, modifications from the FIFA 11+ to the NDW involved an increased number of vertical jumps in addition to a series of squats and lunges. This may have improved jump technique and strength in our largely untrained population. Close associations have been found between muscular strength and other various physical components, including muscular power and jump ability in the physical development of youth athletes (73). Muscular strength has also been reported to be an important factor for correct movement technique (73). Therefore, as vertical jumping plays an important role in the requisite performance of netball movements (139) an increase in vertical jump height would likely be associated with improved performance on court in netball. Additionally, an increase in lower body muscular power may also contribute to injury prevention (88). The improvement in vertical jump height after the implementation of a neuromuscular warm-up programme supports the work of Myer et al. (2005) who showed simultaneous improvements in vertical jump height and decreased varus and valgus torques at the knee, both biomechanical measures related to injury risk in sportswomen. A programme that places an emphasis on improving movement technique, such as the NDW, could alter knee biomechanics when jumping and landing resulting in performance enhancement and reduced injury risk. While the effect of the intervention was statistically significant for both vertical jump and prone hold, consideration needs to be given to the practical implications of these changes. The magnitudes of these changes were in the range of 10-20% for both measures which gives some indication that they are likely to improve performance.

Smaller, yet significant, within-group differences were found in both the intervention and control groups. The Y-balance was found to significantly improve in both groups (INT: ES= 0.34, CON: ES= 0.63). The star excursion balance test (SEBT), or simplified Y-balance test, is a common measure of balance in comparable studies (4, 10, 65, 72, 120). Balance is critical in sporting performance and reducing injury risk (16). Movements performed in sport challenge the body's postural control system creating different balance requirements to successfully complete sporting tasks (16). A unique rule that distinguishes the sport of netball from other similar sports, such as basketball, is the footwork rule. When a player lands with the ball in their hands the first foot they land on is termed the "grounded foot" and this foot must stay on the ground or in the air until the player has released the ball. Re-grounding the grounded foot, while still in possession of the ball is a "step" which results in turn-over of the ball. Similarly, a hop, slide or drag of the grounded foot is not permitted (95). Therefore, upon receiving a pass a player must maintain balance and stability while rapidly decreasing horizontal velocity to come to a complete stop to avoid violation of the footwork rule (134). As balance is an important physical component for successful performance in netball, normal netball training may have been enough stimulus for Y-balance to improve in both intervention and control groups. Previous studies have failed to show improvement in Y-balance after a neuromuscular warm-up in youth women's football players (14.2 ±0.7 years) after 11 weeks, which could have been attributed to insufficient stimulus and low player attendance at training sessions (72).

Improvements in change of direction of up to 5% (T-test) (10, 114) following the FIFA 11+ have been reported previously and the recently introduced "Kids" version of the FIFA 11+ has also been shown to improve horizontal jump performance (120). This contrasts our lack of significant within-group or between-group differences in change of direction (T-test), horizontal jump and TTS. There are several possible explanations for the lack of improvements we observed. Methodological issues involving the length of the intervention and the progression of levels within the intervention possibly did not provide enough training stimulus to induce substantial or meaningful changes in some performance measures. Firstly, the length of the intervention was limited by the NZ school term schedule. Therefore, the intervention period of this study was seven weeks which is in the slightly lower range compared to previous studies where the intervention has run from 4, 6, 10, or 12 up to 30 weeks (66, 114, 131, 154, 157). A comprehensive neuromuscular training programme that included plyometric and movement, core strengthening, and balance, resistance and speed training, was found to improve measures of performance and lower extremity biomechanics (up to 92%) after six weeks (88). In comparison to the current study, the training volume was much higher with three 90-minute training sessions performed each week (88). Secondly, the study by Myer et al. (2005) reported on the importance of exercise progression (duration, volume, intensity) to achieve successful outcomes of a neuromuscular programme. The NDW intervention was prescribed at level one due to the young training age and lack of training experience of the participants, and because of the training inexperience there was no progression to level three in the seven-week intervention period. In comparison, previous studies involving the FIFA 11+ have either started at level three or progressively moved from level one to level three over the course of the intervention (10, 65). There is a strong focus on training vertical direction in the NDW, with emphasis on jump and land techniques. This could explain the significant decrease in horizontal jump performance in the intervention group. There are broad (horizontal) jumps in the NDW, however they are a level three exercise and as the intervention group only performed exercises prescribed at level one, only vertical jump variations were performed. This represents a lack of progression that would likely have occurred if a netball team followed the NDW outside of the confines of this study over an entire season or across multiple seasons. Additionally, the decrease could have been attributed to variation in testing performance.

Furthermore, as discussed in a previous study (72), there is no standard testing battery that exists between studies investigating the effect of neuromuscular warm-ups on performance. The tests selected in this study were used in earlier research investigating the FIFA 11+ and therefore used to enable comparison. However, they are not netball specific tests and more appropriate tests such as single leg hop, or a change of direction test emphasising rapid acceleration/deceleration may be better at measuring change in performance following the NDW. Additionally, some of the more difficult tests may have needed more familiarisation than the testing time constraints allowed.

Sprint (10 and 15 m) time also significantly improved in the control group but not in the intervention group, and neither group improved over the other sprint distances. There was a significant increase in 20 m sprint time in the intervention group. Similar studies involving adolescent women's football players have also failed to show improvements in sprint performance at any distance following a neuromuscular warm-up programme (72, 131). These warm-ups, like the NDW, do not contain any specific sprint training exercises compared to the FIFA 11+ which includes a 40 m run and a sprint-specific exercise (bounding). Therefore, it is a possibility that these warm-up programmes do not contain enough training stimulus to elicit changes in sprint performance. This is in contrast to improvements of approximately 2% in 20 m sprint times found in previous FIFA 11/11+ intervention studies involving male football players (10, 66). Significant improvements in 5 and 30 m sprint times by 8.9% and 3.3%, respectively have also been found in male futsal players following a 12-week intervention of FIFA 11+ (114). As short sprints are a common movement in netball (139), exercises that help to improve sprint technique, such as bounding, could be included in the warm-up programme to help improve sprint performance.

Finally, the effect of neuromuscular warm-up programmes in previous studies has been shown to be influenced by compliance. Compliance in our study was recorded by the individual participant being present at each training session. Based on a threshold of 75% attendance, overall participant compliance to the warm-up programme was low for both intervention (56%) and control (67%) groups. These compliance rates were lower than those reported by previous studies (72-92%) (66, 148). Further exploratory analysis of our data, which only included participants who meet the 75% compliance threshold, did not reveal any additional benefit of the NDW.

Limitations

There were limitations to this study that should be considered when interpreting the results. Due to an unanticipated higher drop-out rate the sample size was small and could have increased the likelihood of type II error or failed to find an effect when in fact there could have been one. Additionally, there is also a possibility of a training effect as the participants were young untrained athletes.

Conclusion

In conclusion, this study provides preliminary evidence that the NDW is more effective for improving some physical performance measures in youth netball players than a traditional warm-up. Players improved prone hold and vertical jump performance which are both important physical components in netball. Therefore, performing the NDW could lead to improvements in netball performance. As the programme is included in a warm-up format, it is relevant for netball coaches to consider implementing in their training programmes. This was the first study investigating the effect of the NDW on performance in youth netball and future research is recommended addressing the methodological issues raised.

Chapter 5: The Effect of the NetballSmart Dynamic Warm-up on Isokinetic Knee Strength in Youth Netball Players

This chapter comprises the following brief report in review in *New Zealand Journal of Sports Medicine.*

Reference:

McKenzie, C.R., Brown, S.R., Whatman, C., Brughelli, M. (2019). The effect of the NetballSmart Dynamic Warm-up on isokinetic knee strength in youth netball players. *New Zealand Journal of Sports Medicine*: [in review].

Overview

The purpose of this study was to investigate the effect of the NetballSmart Dynamic Warm-up on isokinetic knee strength in female youth netball players. High school netball players (*n*= 23) participated in a seven-week intervention study. Isokinetic dynamometry was used to assess concentric and eccentric peak torque measures of the right leg during seated knee flexion and extension actions at 60º/s. There were no significant differences found between pre- and post-measures in peak torque, angle of peak torque and hamstrings-to-quadriceps ratio. Therefore, there was no improvement in knee strength after performing the NetballSmart Dynamic Warm-up. This could indicate that the programme does not contain sufficient stimulus to improve maximal strength in female youth netball players.

Introduction

Weakness about the knee, in particular the hamstring, has been shown to be associated with increased anterior cruciate ligament (ACL) injury risk in female athletes (87). The combination of increased internal tibial rotation, greater quadriceps activity, and low hamstring to quadriceps ratio while landing could contribute to the explanation of why female athletes have a higher incidence of non-contact ACL injuries (89). Netball is an intermittent court sport, that is predominantly played by females, involving explosive movements such as sprinting, cutting, change of direction and pace, and jumping (139). Court restrictions confine players to positional areas of the court, often requiring players to abruptly stop to avoid going off-side. Additionally, upon receiving a pass, a player must rapidly decrease horizontal velocity to come to a complete stop to avoid violation of the unique footwork rule (134). To perform such movements, deceleration capability is required.

During deceleration, the forces applied to the body can be very large, especially when the time over which these forces are absorbed is short (54). Deceleration requires the muscles to act like a shock-absorbing structure or brake by eccentrically contracting (68, 149). The muscle-tendon unit assists in the dissipation, or temporary storage of energy during deceleration (68). Injury can occur when the forces needed to decelerate the body are greater than the muscle-tendon unit can tolerate (68). Recurring hamstring injury has been associated with greater impairment of eccentric strength, compared to concentric strength, suggesting improvements in eccentric strength may reduce injury risk (68). Eccentric strength training can lead to increases in tendon stiffness and an improved ability to absorb energy at the musculotendinous junction; as well as enhanced muscular strength, power and jumping, and sprinting performance (68, 149).

To help prevent injury and improve performance in netball, Netball New Zealand have implemented a warm-up programme (NetballSmart Dynamic Warm-up). A detailed manual can be found on the official website (93). The program largely incorporates a strength component intended to improve the players' quadriceps and hamstrings strength; consisting of exercises such as Nordic hamstring, squats, and lunges. Similar warm-up programs, completed two to three times per week, have been shown to decrease lower limb injuries by at least 40% (9). Currently there is no research investigating the effect of the NetballSmart Dynamic Warm-up on knee strength. Therefore, the purpose of this study was to determine if the NetballSmart Dynamic Warm-up can improve isokinetic knee strength in youth netball players.

Methods

Experimental approach to the problem

To investigate the effect of the NetballSmart Dynamic Warm-up on isokinetic knee strength in a group of 23 female youth netball players, isokinetic data was collected from all participants the week before and the week following a seven-week intervention. The warm-up programme was performed three times each week and was delivered by a qualified strength and conditioning coach twice per week before training, and once per week by the team coach before games. The warm-up programme consisted of four parts: Part A- four different strengthening and balance exercises, each with three levels of increasing difficulty; Part B- running exercises at slower speeds and some controlled partner contact; Part C- dynamic preparation exercises, including dynamic stretches and plyometric movements, each with three levels of increasing difficulty; and Part D- netball specific exercises involving running at faster speeds, cutting and stopping. The warm-up took approximately 15-20 minutes to complete per session. The overall compliance rate of for completing the warm-up at least once per week was 65%.

Participants

A total of 23 female youth netball players (mean ±SD: age 13.09 ±0.29 yr, height 165.74 ±5.98 cm, body mass 52.87 ±9.02 kg) were recruited through local secondary schools for this study. All participants were training and competing in a secondary school netball programme and were healthy and free from injury in the last six months. Prior to participation, all participants and guardians were fully informed of the experimental procedures before giving their informed consent and assent. This study was approved by the Auckland University of Technology Ethics Committee.

Methodology

Following a standardised warm-up, a Humac Norm dynamometer (Lumex, Ronkonkoma, NY, USA) was used to assess isokinetic knee extensor and flexor strength of the right leg. Participants were seated and strapped to the device with the lateral femoral epicondyle aligned with the dynamometer axis of rotation (86). A 90º range of knee motion (0º = full extension) was set for all tests and gravity adjustments were made (13). The testing protocol consisted of concentric and eccentric actions at a fixed angular velocity of 60°/s (5 repetitions). Familiarisation required three movements at an individually perceived 75%, 90% and 100% of maximum exertion at each position (14). During the test, verbal feedback was given to each participant to encourage maximum effort at each trial. Participants had 45 to 60 s rest between each trial. As per previous research (14), torque-angle curves with a fourth-order polynomial were fitted using a custom-made LabView program (Version 11.0, National Instruments Corp, Austin, TX, USA) to identify peak torque and the angle of peak torque using the averages of the last 4 repetitions. Hamstring-to-quadriceps ratios (H:Q ratio) were calculated by dividing the concentric peak flexion torque by the concentric peak extension torque using Excel (2010, Microsoft, Redmond, WA, USA).

Statistical analysis

The Statistical Package for the Social Sciences (SPSS) (IBM SPSS Statistics v. 25; IBM Corporation, Chicago, IL) was used to perform all analyses. Normality was tested using the Shapiro-Wilk test and by visual review of histogram graphs. Data was not normally distributed and therefore the non-parametric Wilcoxon Signed Rank Test was used to determine pre-post differences in all measures. Mean differences with 95% confidence intervals and Hedges' g effect sizes (ES) were reported (Table 13). The following scale was used to interpret the ES's 0.2-0.59 (small), 0.6-1.19 (moderate), 1.2-1.99 (large), 2.0-3.99 (very large), >4 (extremely large) (58). The threshold of $p<0.05$ for statistical significance was set for all analyses.

Results

All results are presented in Table 13. No significant effect of the intervention was found between pre-and post-knee peak torque measures. The H:Q ratio was also non-significant. Additionally, there were no significant changes in the angle of peak torque.

Table 13. Mean pre-post differences (*n*= 23).

Variable	Pre Test Mean ±SD	Post Test Mean ±SD	Difference Mean + 95% CI	ES Hedge's g	P value
Knee peak torque (N.m)					
Concentric Flexion	54.88 ±15.23	53.28 ±14.38	-1.60 (-5.0 to 1.8)	-0.11	0.27
Concentric Extension	103.60 ±24.73	103.81 ±22.44	0.22 (-4.7 to 5.1)	0.01	0.90
Eccentric Flexion	71.10 ±20.50	69.85 ±22.20	-1.25 (-5.8 to 3.3)	-0.06	0.35
Eccentric Extension	127.18 ±40.17	117.00 ±28.68	-10.18 (-21.9 to 1.6)	-0.29	0.08
Angle of peak torque					
Concentric Flexion	41.51 ±15.52	37.88 ±15.03	-3.63 (-10.0 to 2.7)	-0.23	0.25
Concentric Extension	66.96 ±6.40	62.66 ±7.62	-4.30 (-7.6 to -1.0)	-0.60	0.14
Eccentric Flexion	34.53 ±12.82	34.23 ±16.38	-0.30 (-7.2 to 6.6)	-0.02	0.93
Eccentric Extension	66.37 ±10.85	59.22 ±13.40	-7.15 (-14.9 to 0.5)	-0.58	0.07
Hamstrings:quadricep ratio	0.53 ±0.11	0.52 ±0.09	-0.02 (-0.06 to 0.02)	-0.10	0.25

Values are mean ±SD; ES=effect size; CI=confidence interval

Discussion

The main findings of this study were that no improvements in concentric and eccentric knee peak torque or angle of peak torque were observed after the introduction of the NetballSmart Dynamic Warm-up in female youth netball players. These findings are in agreement with a previous study in female football players of a similar age (17.1 ±0.8 yr) that did not show improvements in knee concentric and eccentric maximal strength after 10 weeks of the FIFA 11 (133). A likely explanation for the non-significant findings in the current study could be the lower training stimulus was not enough to elicit changes in strength. The exercise volume and intensity may have limited the potential for improved maximal effort strength.

Previous studies by Daneshjoo et al. (2013) and Reis et al. (2013) have shown improvements in knee strength after a similar warm-up programme, the FIFA 11+. Concentric hamstring strength in young professional male football players increased after 24 sessions of the FIFA 11+ (19). Quadriceps concentric and hamstring concentric and eccentric strength was also found to improve in adolescent male futsal players after 12 weeks of the FIFA 11+ (114). In comparison to the current study, both studies (19, 114) involved adolescent male futsal or football players. Therefore, the differences in findings may be due, in part, to gender, age and training experience. As the NetballSmart Dynamic Warm-up is based on the FIFA 11+, the programmes contain similar exercises; however, there are differences in the prescription of the exercises between the programmes. The FIFA 11+ has more sets and repetitions compared to the NetballSmart programme, increasing the volume and intensity of each exercise. For example, FIFA 11+ prescribes two sets of squats and walking lunges and 12-15 repetitions of hamstrings strengthening exercises, whereas NetballSmart prescribes one set and 7-10 repetitions, for the respective exercises. Therefore, if the intention of the NetballSmart programme is to improve maximal effort strength as well as prevent injury, the design of the programme needs to contain the correct training stimulus to promote this. Additionally, it has been suggested that rescheduling and completing the strength section (Part 2) of the FIFA 11+ warm-up programme at the end of training sessions improved player compliance and reduced the number of severe injuries and total injury burden (150). The rescheduling was to address implementation barriers that had been identified, including programme duration, exercise difficulty/fatigue, and boredom (150). Therefore, a rescheduling of the strength section could be a consideration for the NetballSmart Dynamic Warm-up, particularly if the exercise stimulus can be increased without the concern of fatigue prior to training.

Furthermore, the findings of this study highlight the importance of 'off-court' training (i.e. training that is supplemental to court training/skill specific training sessions) to contribute to the enhanced physical performance and reduction of injury risk in youth netball players. Even though the approach of including neuromuscular programmes in a warm-up format has been suggested to integrate and associate the exercises as standard practice (34), the warm-up programme in this study did not provide enough stimulus to improve strength. The NetballSmart Dynamic Warm-up has been previously shown to improve some physical performance measures, however, more work is required to achieve total physical preparation outside of court training and the warm-up programme itself. Findings support the need for further "off-court' training for netball players to enhance their "on-court" physical abilities.

Limitations

Although this study did not show improvements after a seven-week programme, we suggest further research addressing the short-term nature, low player compliance, and training volume and intensity of this intervention. Furthermore, the study could be strengthened by the addition of a control group.

Practical applications

These findings suggest a greater training stimulus is needed to produce improvements in knee strength. This could be achieved by adding more sets, with adequate rest time, to exercises during each training session. This would increase the overall volume of the exercise. It is also important to ensure the exercises are being performed correctly. As the participants in this study were younger, untrained female netball players, it is possible the movements were not being performed with maximal effort (low intensity). Therefore, it is important to have a coach or qualified trainer who understands the exercise and correct technique when required. If such training protocols are designed to help improve performance, players and coaches may be more encouraged to participate in the programme with the potential for higher player compliance. Coaches may also be able to create ways to ensure the exercises are engaging to ensure youth athletes engage in higher intensity exercises. For example, allowing the athletes to lower for longer during the Nordic hamstring will increase the length of the muscles and increase the intensity (101). Consideration could be made for the rescheduling of the warm-up programme, as well as incorporating 'off-court' training into youth netball training schedules.

Conclusion

In conclusion, the NetballSmart Dynamic Warm-up did not improve isokinetic knee strength in youth netball players. This was the first study to investigate the effects of the warm-up on isokinetic knee strength. Findings have shown that the exercise stimulus in the warm-up may not be sufficient to improve strength in this group and has highlighted the importance of “off-court” training.

Section 3: Implementation of Neuromuscular Warm-up Programmes

Chapter 6: Implementation of the NetballSmart Dynamic Warm-up: The Role of the Coach

This chapter comprises the following paper submitted to *International Sport Coaching Journal.*

Reference:

McKenzie, C.R., Whatman, C., Walters, S., Brughelli, M. (2019). Implementation of the NetballSmart Dynamic Warm-up: The role of the coach. *International Sport Coaching Journal*: [submitted].

Overview

Coach support is crucial to the successful implementation of injury prevention programmes in sport. Since the implementation of the NetballSmart Dynamic Warm-up in New Zealand (NZ) there has been no research targeting the experience of coaches. Therefore, this study investigated coach knowledge and attitudes towards injury and injury prevention in netball, as well as their experiences with the warm-up programme. A cross-sectional survey with a mixed method approach was used to collect and analyse responses from 56 netball coaches. Poor technique was perceived to be the most common injury risk factor in netball, and almost all coaches (*n*= 54) believed that a warm-up can reduce injuries. The ankle was correctly reported as the most common lower limb injury (67%) but experienced coaches or coaches who were also netball players did not have better knowledge of injuries. The majority of coaches felt their personal coaching experience was sufficient to be able to coach the warm-up and 81% of coaches reported observing improvements in player ability after using the warm-up. A significantly higher proportion of coaches who were also netball players reported they would deliver the warm-up one to two times per week. Three dominant themes were identified in the qualitative data: 1) the importance of coach education and understanding of injury prevention; 2) long-term player development; and 3) practical implementation of the NetballSmart Dynamic Warm-up. This study provided initial coach feedback on the NetballSmart Dynamic Warm-up and will assist with its future development.

Introduction

Netball is the most popular women's sport in New Zealand (NZ), with a reported 144,358 affiliated players in 2017 (92). It is a physically demanding game that involves jumping and landing, sprinting with quick changes of direction, accelerating and decelerating (139). The abrupt landing and decelerations performed while playing can put players at particular risk of lower limb injury (139). The most common lower body injury site in netball is the ankle (84%) (62) and netball has one of the highest rates of anterior cruciate ligament (ACL) injuries in NZ sport, with around 400 netball players having ACL reconstruction each year (90). The rising number of sports-related injuries in NZ has prompted the Accident Compensation Corporation (ACC), a NZ Crown entity responsible for managing the country's universal no-fault accidental injury scheme, to implement various injury prevention programmes (7). Netball New Zealand (NNZ) and the ACC have specifically implemented the NetballSmart Dynamic Warm-up, an injury prevention programme aimed at reducing the number of injuries in netball. The NetballSmart warm-up was adapted from the highly researched FIFA 11+ programme using the four key components of strengthening, running, dynamic preparation and sport-specific preparation.

Coach and player adherence is key to the successful implementation of injury prevention programmes into real-world sports settings (80). Although some coaches consider injury prevention to be the responsibility of physiotherapists or medical support staff (146), it is the coach who determines whether or not injury prevention programmes are delivered to players via training (33, 34). A study by Finch et al. (2011), investigating injury prevention in football, promoted the approach of delivering injury prevention training programmes as a part of routine football activities (i.e. warm-up) to integrate and associate the exercises as standard practice. Thus, coaches are key in the translation of injury prevention programmes into practice (152). From a player perspective, players need to attend training, adhere to the programme and include it in their regular individual training (33). Achieving the full potential of an injury prevention programme will not be possible if coaches and players do not first adopt the programme, then correctly implement it, and finally maintain its regular use (98). There is research to support an inverse dose-response relationship between injury prevention programmes and knee injury, thus maximum adherence to injury prevention programmes is important to achieve the best outcome (136). A 72% reduction in injury risk was reported in youth football players who had a high adherence rate to an injury prevention programme, compared to players with less adherence (132). The motivation, choices and actions of a coach are likely to influence the adherence of a team to an injury prevention programme (129). A correlation was found between coaches with positive attitudes towards injury prevention and a higher adherence to injury prevention programmes, which resulted in a significant reduction in injury in youth football (129).

Given the important role of the coach in the injury prevention process, coach knowledge and awareness of injuries and injury prevention is important (80, 102). Previous studies have reported limitations in female football coach knowledge and awareness of injury prevention, or a lack of confidence to be able to implement an injury prevention programme (123, 151). White et al. (2014) found coaches to have strong positive attitudes towards teaching a correct landing technique programme in netball; however, they were less convinced of their ability to do so. These findings highlight an apparent gap in the translation of research into real-world contexts. Even though an injury prevention programme is shown to be evidence-based, the same results are not guaranteed in real-world sporting environments, especially if not implemented correctly by coaches and players (146).

To assist with the implementation of injury prevention programmes from the research-field to the sports environments, sports injury frameworks have been proposed (31-33). These frameworks include: Translating Research into Injury Prevention Practice (TRIPP) (31); Reach, Effectiveness, Adoption, Implementation, Maintenance (RE-AIM) (32); and RE-AIM Sports Setting Matrix (33). There are six stages in the TRIPP model (31) with sports injury research highlighting stages five and six as particularly important (33). Stages 5 and 6 help to provide an understanding of barriers and facilitators to the implementation and sustainability of injury prevention programmes (32, 33). Currently, much of the injury prevention literature lacks the adoption and maintenance components of the RE-AIM framework and thus this is an area where further research is needed (98). It must be acknowledged that sometimes, in order to translate programmes to different sports environments and overcome barriers, adaptations to the programme are needed. However, these adaptations must ensure the fidelity of the programme remains (98).

Since the implementation of the NetballSmart Dynamic Warm-up in NZ, there has been no research into the adoption and maintenance of the programme. The experiences and thoughts of netball coaches towards the NetballSmart Dynamic Warm-up have not yet been examined, and their knowledge and attitudes towards injury prevention remains unclear. Therefore, the purposes of this study were to; 1. Examine coach knowledge and attitudes towards injury and injury prevention in netball, and 2. Evaluate the experience of coaches delivering the NetballSmart Dynamic Warm-up.

Methods

This study used a cross-sectional survey study design with a mixed-method approach, involving netball coaches who had delivered or were currently delivering the NetballSmart Dynamic Warm-up. Open-ended questions were included in the questionnaire to provide greater understanding of coach experiences, attitudes and thoughts towards injury and specifically the injury prevention programme.

Participants

Participant recruitment was primarily through the Netball New Zealand database. All coaches who had attended a NetballSmart workshop were emailed an invitation to participate, along with the questionnaire. A total of 54 questionnaires were completed and submitted. Consent was given upon completion and submission of the questionnaire. This study was approved by the Auckland University of Technology Ethics Committee (15/458).

Data collection

A questionnaire was developed to evaluate coach knowledge and attitude towards injury in netball and to gain an insight to their experiences and thoughts of the NetballSmart Dynamic Warmup. All questions were based on a previously reported survey using similar questions (123). The questionnaire included both closed and open-ended questions and consisted of two main parts. The first part focused on the coaches' knowledge and attitudes of injury and injury prevention in netball. The second part asked coaches about their experiences with, and thoughts on, the NetballSmart warm-up. The level of individual coaching experience (number of years coaching) was also collected from each participant. The questionnaire was piloted on an experienced coach and an expert in the NetballSmart Dynamic Warm-up. It was also reviewed by a faculty member experienced in questionnaire design. The feedback was used to produce the final version of the questionnaire. Participants were sent a link to complete the questionnaire electronically via Google Forms. All data was then automatically collated into a spreadsheet for analysis.

Data analysis

Data from the online questionnaires were exported into a Microsoft Excel spreadsheet (2010, Microsoft, Redmond, WA, USA). Descriptive statistics were used to analyse responses to questions in the questionnaire. Chi-square tests for independence were used to calculate differences in proportion of responses between; 1. experienced coaches (>5 years' experience) and in-experienced coaches (<5 years' experience), and 2. Coaches who also play netball and coaches who do not play netball. The Statistical Package for the Social Sciences (SPSS) (IBM SPSS Statistics v. 25; IBM Corporation, Chicago, IL) was used to perform all analyses. An online calculator was used for further analysis to determine percentage differences and confidence intervals (95%) (https://www.medcalc.org/calc/comparison_of_proportions.php). The threshold of $p<0.05$ was set for statistical significance. There were also six open-ended questions included in the questionnaire. Analysis of the open-ended questions followed a qualitative procedure for both deductive (seeking specific answers to questions) and an inductive form of thematic analysis (11). The inductive analysis examined the data to identify key patterned meanings and common themes using a six-phase analytic process (11). The six phases of the process were: familiarisation of the data; generating codes; constructing themes; reviewing potential themes; defining and naming themes; producing the report (12). We consulted with experts on thematic analysis before examining the data.

Results

A total of 54 coaches responded to the questionnaire. Of these, 46% (*n*= 25) had five or more years' netball coaching experience. Just over half of the coaches (52%, *n*= 28) were also netball players.

Knowledge of injury risk factors and prevention in netball

Of the coaches who completed the questionnaire, 87% perceived poor technique (during movement) to be the most common injury risk factor in netball (Figure 4). Inadequate warm-up and a lack of stretching/flexibility were also perceived by most coaches (81%) to be common risk factors. Almost all coaches (98%) believed that a warm-up can reduce injuries in netball. The ankle was reported as the most common lower limb injury by 67% of coaches, with the remaining coaches believing it was the knee. Players were perceived to be primarily responsible for their own injury prevention (74%) with only 22% of coaches indicating that they thought they were responsible for injury prevention (Figure 5). Half of the coaches perceived male and female athletes to have the same overall injury risk. If coaches were also players, this did not increase the proportion who correctly answered the injury related questions regarding common injury (mean difference= 5%; 95% CI= -19-28%; p= 0.70) and male/female injury risk (mean difference= 8%; 95% CI= -18-32%; p= 0.56). Additionally, having more than five years' coaching experience did not increase the proportion of correct answers (mean difference= 10%; 95% CI= -15-33%; p= 0.44 and mean difference= 4%; 95% CI= -23-28%; p= 0.79, respectively).

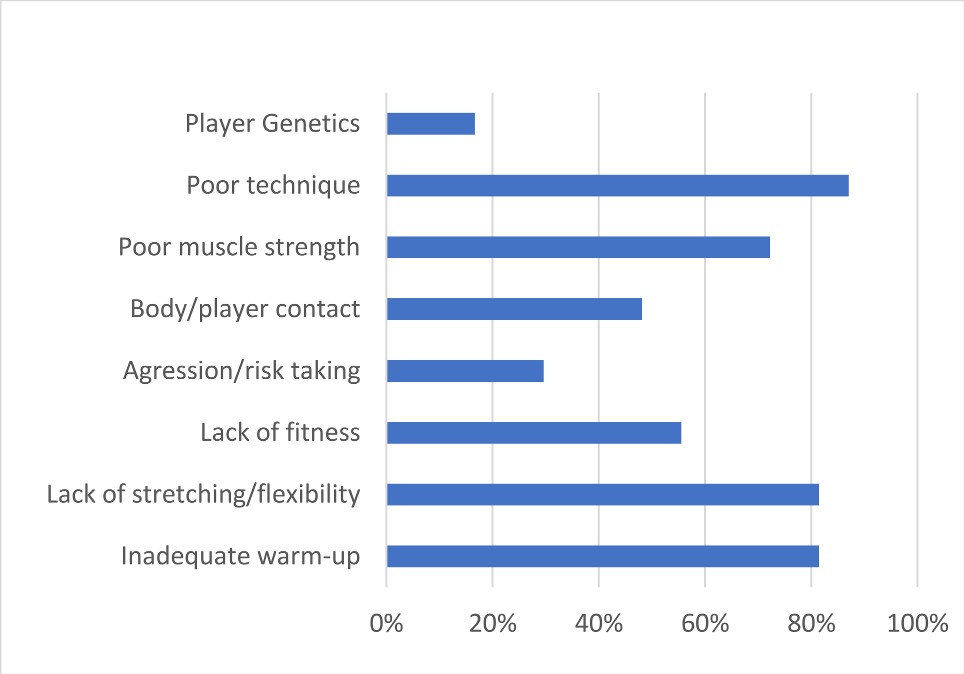

Figure 4. Percentage of coaches who considered various factors risks for injury in netball.

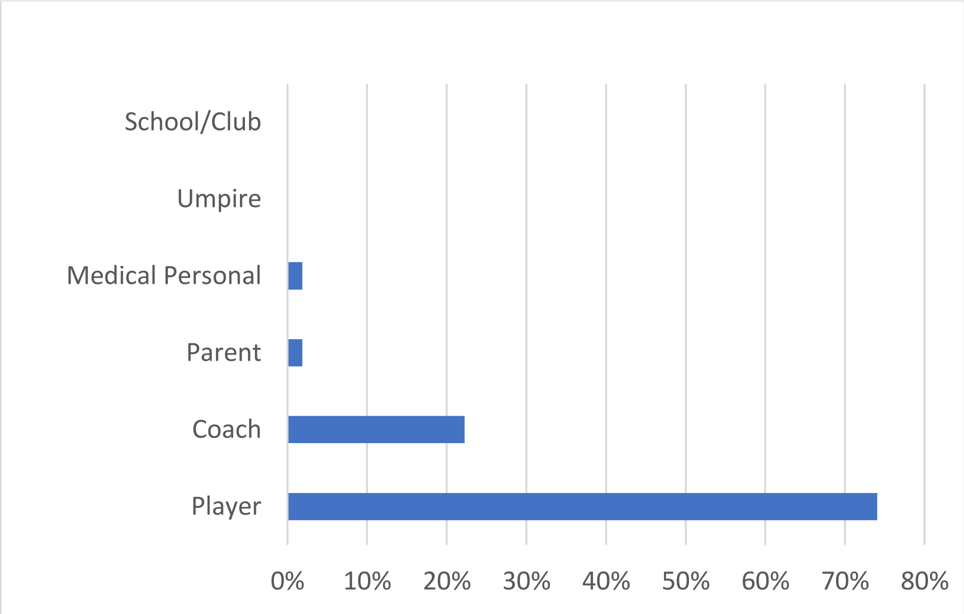

Figure 5. Percentage of coaches who thought various stakeholders were responsible for injury prevention in netball.

Education and understanding

Most coaches (93%) felt their personal coaching experience was sufficient to be able to coach the warm-up. Additionally, 91% of coaches felt confident in delivering the warm-up all or most of the time. A dominant theme identified related to the importance of both coach and player education and understanding of the NetballSmart Dynamic Warm-up. The need for further coach education was illustrated by the comment:

"…we do need more experts out there…making sure the teachers/coaches are doing this correctly and not teaching kids the wrong movement".

Furthermore, the importance for player understanding was highlighted by the comment:

"Educate the players around the WHY of the warm-up- information is the key".

Long-term development

In addition to injury prevention, some coaches viewed the warm-up as a way of creating good training habits from a young age, which could be transferred to other sports. Long-term development was another dominant theme identified from the data. Most coaches (81%) reported observing improvements in player ability after using the warm-up. The major improvements (38%) were seen in movement and technique. Some coaches attributed improvements in game play to physical improvements, suggesting the warm-up could help with player development. Furthermore, the issue of breaking out-dated training habits in older athletes was also indicated by some coaches. Most coaches (83%) believed the NetballSmart warm-up programme was applicable to all age groups, however the age groups considered to be most suited to the warm-up (46%) were the Year 9 and 10 school-age groups (14-15 years). The warm-up was also seen to be considered as best practice, and the continuation from development netball (Fun Ferns) to National (Silver Ferns) level netball was acknowledged to support long-term use and development through a consistent approach.

Practical implementation

The third dominant theme identified in the survey was practical implementation. There were some practical issues with the implementation of the warm-up reported by coaches. Time to complete the warm-up (37%) and having sufficient space (28%) to perform the warm-up were perceived to be the most common barriers (Figure 6). The warm-up was considered too long by some coaches, taking time away from skill work. Coaches were also critical regarding the content in the warm-up, reporting that it was boring or too repetitive and had no upper body or ball work, which could lead to player complacency and the warm-up being performed with poor quality. The structure of the warm-up was also reported as being difficult to run with uneven numbers. Some coaches reported on strategies to overcome barriers associated with the implementation of the warm-up. These strategies included adapting the warm-up to a smaller space, allowing enough time in the practice to make the warm-up a priority, adjusting the repetitions of the exercises and including more ball-work. Even though a number of implementation issues were reported, the majority of coaches (89%) said they will continue to use the warm-up in the future. A significantly higher proportion of coaches who had been players reported they would deliver the warm-up one to two times per week (mean difference= 31%; 95% CI= 8-51%; p= 0.01).

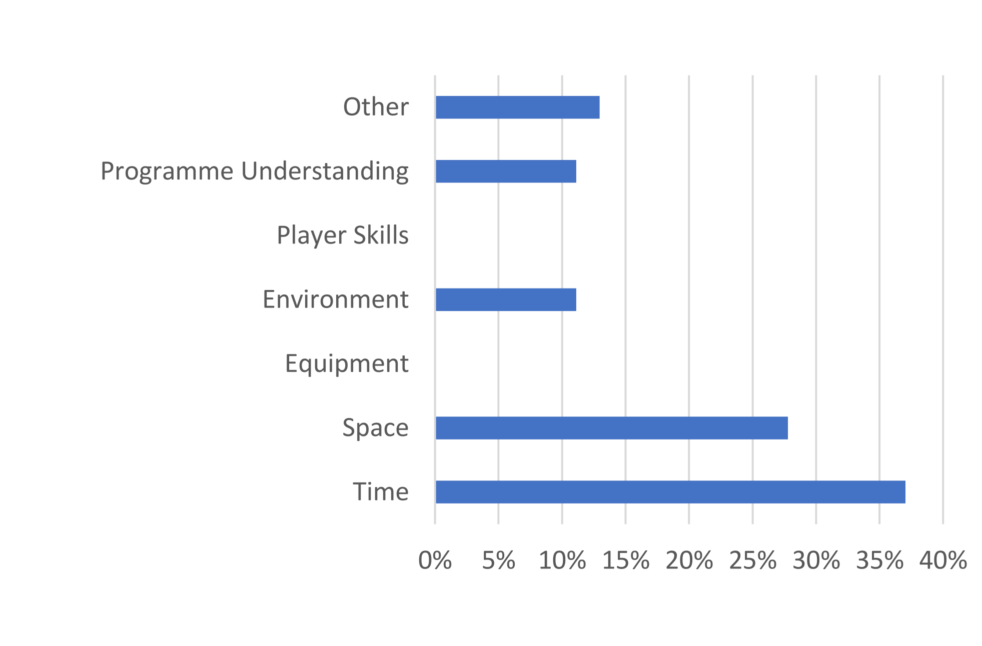

Figure 6. Percentage of coaches who perceived various barriers to implementation of the warm-up.

Discussion

The knowledge of injury risk factors and injury prevention in netball varied between coaches in this study. Only 67% reported that the ankle was the most common lower body injury site and 50% presumed males and females have the same injury risk, showing a possible lack of knowledge in this group of coaches. A considerable gap in knowledge regarding knee injury prevention has also been identified in female soccer players, their parents and coaches (102). However, a large percentage of coaches in the current study did believe that a warm-up can reduce injuries in netball, which is in accordance with the findings by McKay et al. (2014) who identified inadequate warm-up as an injury risk factor. Knowledge regarding injury risk could help promote adherence of injury prevention programmes (80). Thus, it is important that netball coaches have some knowledge of injury and injury prevention strategies to help with the implementation of the NetballSmart programme.

Poor movement technique was reported as the most common injury risk factor in netball by coaches. As netball is a sport that involves repetitive landing tasks with fast decelerations, poor landing technique can lead to injury (106). A study by Finch et al. (2011) reported that senior male Australian Football players and coaches were largely unaware of the most recent evidence on the effect of landing and balance training in lower limb injury prevention. However, they were willing to undertake exercises to prevent lower body injury as long as it did not reduce training time. Some coaches in our survey agreed that the time taken to complete the warm-up, focusing on movement techniques rather than teamwork and other skills, reduced valuable practice time. Therefore, implementation strategies aimed at maximising participation in correct landing programmes in junior netball should emphasise the benefits of learning correct landing technique (152).

Stretching was also considered a common injury risk factor in the current study (81%). Players and coaches in previous studies have also considered stretching, along with longer warm-up and general fitness, as important injury prevention strategies (80, 102, 146). Additionally, static stretching during warm-up was performed frequently in an observational study by Slauterbeck et al. (2017), and a study by Orr et al. (2013) reported that 95% of recreational soccer coaches thought that stretching would prevent knee injuries. However, stretching during warm-up has not been shown to produce clinically meaningful reductions in injury risk (110). Thus, these findings indicate there is either a considerable gap in knowledge in injury prevention (102) or that accurate evidence of current strategies is not being effectively disseminated to the target audience (80, 102). This includes the addressing of incorrect or outdated beliefs (80) which could help to break obsolete training habits of older athletes reported by coaches. Coaches are considered key influencers in the adoption of appropriate injury prevention strategies (151) and are therefore crucial in the dissemination of new knowledge; however only 22% of coaches in this study considered themselves responsible for injury prevention.

Even though coach delivery of injury prevention programmes may be the most practical method of reaching a large number of community-based athletes, coaches must be able to understand and correctly translate information beyond just the content of such programmes (80). A dominant them of coach education and understanding was the importance of coaches being able to explain the reason, or the 'why', for performing the injury prevention programme. This was highlighted by the experience of one coach:

> *"I think it has worked really well throughout the season and has not only strengthened our players but also taught new players and old seasoned players the importance of balance and proper warmups. Overall our injuries have decreased this season and I would like to think it is because we are teaching our ladies how to warm-up properly".*

Most coaches in this study felt their coaching experience was sufficient (93%) and they were confident in their ability (91%) to deliver the warm-up. However, identified gaps in knowledge highlight the importance of further education on injury risk and prevention. Football coaches have also acknowledged a lack of education regarding injury prevention strategies and an expressed desire for further education (146). It has been suggested that coach accreditation through courses could be implemented or improved to support the implementation of injury prevention programmes (123). It has been suggested that organisations considering the promotion of injury prevention should utilise a community coach education option to reach large numbers of community level players (46). Coach workshops can also influence coach attitudes, perceived behavioural control and intent to implement an injury prevention programme (37). Although it is highly recommended, it is not compulsory for netball coaches in NZ to complete a coach accreditation course or workshop. For coaches in the current study who had completed a NetballSmart workshop, many suggested a refresher course would be useful.

Coaches reported observing an improvement in player ability, specifically movement and technique, after using the warm-up. Saunders and colleagues (2010) also reported that coaches believed a lower-limb injury prevention programme in netball improved their players ability to apply correct landing techniques during the game. Dynamic and functional balance among 13-18-year-old female football players was also found to improve with a 20-minute neuromuscular warm-up programme (132). Evidence that injury prevention programmes benefit both performance and injury prevention is important to implementation (146). The NetballSmart warm-up has been shown to improve vertical jump and prone hold performance in female youth netball players (82). If there is a performance enhancing benefit identified by the coaches, it helps with the perceived value and provides additional motivation for coaches to accept and adopt the programme (123, 132). This allows good training habits to be created from a young age, with one coach commenting that:

> *"Using it [the NetballSmart Dynamic Warm-up] from the start forms good habits throughout the playing years".*

Another identified theme from the qualitative data was long-term development. The adoption from grassroots to elite level could also help with the implementation of the warm-up. The implementation of injury prevention programmes should include role models for both coach education and players (152). Soligard et al. (2010) found that 75% of the coaches in their study were motivated to carry out injury prevention training due to the influence of media and profiled athletes promoting the programme. Coach role models or peer coaches could influence coaches' intentions to deliver injury prevention programmes to their own players (151). For example, if high school coaches or recreational coaches see the NetballSmart programme being delivered at a National level, they may be more likely to use it with their teams. One coach suggested a Silver Fern taking players through the warm-up would help with delivering the programme.

The third dominant theme related to the practical implementation of the warm-up. Barriers to the implementation of the NetballSmart Dynamic Warm-up were identified in the survey. There were two recurring barriers mentioned throughout the coach feedback. These were: 1) space to perform the warm-up, especially before games, and 2) the amount of time required to perform the warm-up prior to training and games. Similar barriers including time and content of the warm-up have been found in previous research (123). Several coaches also reported that the repetitive nature of the warm-up made it boring. Soligard et al. (2010) found that there was a higher probability of low compliance if coaches believed that the programme was too time-consuming, or if the programme did not include enough sport-specific activities. If performed two to three times per week the warm-up has the potential to prevent lower limb injuries by up to 40% (93), therefore it is important to address and reduce barriers to maximise programme compliance.

Coaches commented on adapting and modifying the warm-up to be able to use it in their own coaching environments. For example, one coach decreased the number of sets or reps and another left out the strength section of the warm-up to make it shorter. Adding ball skills was another coaches' way of making the warm-up more interesting. However, coaches require knowledge and understanding to have the ability to be able to adapt an injury prevention programme to their environment. Additionally, the effectiveness of an evidence-based injury prevention programme may change if the programme has been altered. The need to change an injury prevention programme also highlights the problem with the translation of an injury prevention programme from a research context to the real-world environment (123).

Limitations

There were some limitations to this study. Firstly, the sample size was small due to a lower than expected response rate. It may also have been useful to ask coaches about any possible qualifications to support their level of experience. As time was limited, there was no follow up with coaches or focus groups to ask for further information regarding the answers given by coaches. Additionally, further research could involve feedback from players as well as coaches. As player adherence was reported to be an influencer in the implementation of the warm-up, further insights could be gained by including players in future surveys.

Conclusion

In conclusion, the findings of this survey have given an insight to coach knowledge and attitudes towards injury and injury prevention in netball, as well as provided initial feedback on the NetballSmart Dynamic Warm-up programme. Coaches play a key role in injury prevention and gaps in coach injury prevention knowledge were found. It is important to improve coach knowledge to help empower them to be able to implement the warm-up in their own environment. Feedback on the warm-up was generally positive but highlighted that translation of injury prevention programmes from research to real-life contexts is challenging and often requires adapting the programme.

Chapter 7: Discussion and Conclusion

Netball has been identified as a physically demanding sport requiring acceleration, deceleration, cutting, changes of direction, and frequent jumping/landing (44). These physical requirements associated with this popular female sport put players at high risk of injury (52). Ligament sprains, contusions and muscles strains are the most common injury types, with the ankle the most common lower limb injury site (63). As a result, netball players need to be physically well prepared to perform successfully and limit injury risk. To achieve enhanced physical preparation there has been a recent increase in the use of neuromuscular warm-up programmes in several sports, with evidence these programmes can enhance performance and reduce injury risk (10, 76, 128). Commonly these programmes target modifiable performance factors including strength, balance, proprioception and movement quality. Specifically, neuromuscular warm-up programmes have been shown to improve several physical performance measures (10, 23, 66). Given the success of these programmes in real world settings is reliant on high adherence, evidence of performance improvements is an important factor when getting coach buy in. It is well known that coaches are a key stakeholder in the successful implementation of any injury prevention programme (151). The current evidence supporting the use of neuromuscular warm-up programmes is predominantly in males and limited to a small number of sports. A recently developed neuromuscular warm-up, the NetballSmart Dynamic Warm-up, was created by Netball NZ, in association with the ACC, to improve performance and reduce injury in netball. Given the limitations in the literature the overall purpose of this thesis was to determine if the NetballSmart Dynamic Warm-up can improve physical performance measures in youth netball players. Additionally, there was a focus on exploring the role of the coach in the implementation of the warm-up.

A series of studies were conducted to progressively address the overall purpose of this thesis and provide novel perspectives on physical performance and neuromuscular warm-up in youth netball players. To achieve the purpose, it was necessary to first determine the effect of neuromuscular warm-up programmes on physical performance. A review of literature and synthesis of previous findings (Chapter 2) highlighted that neuromuscular warm-up programmes improved some physical performance measures in team-sport athletes. However, there were limitations and gaps identified in the existing literature. Most of the studies were conducted in male football players with little evidence in female athletes and other sports. Furthermore, there was little known of performance measures (e.g. jump, speed, strength) in youth female athletes as the majority of previous studies focused on biomechanical measures of jump/land technique and/or general movement quality changes. Given these limitations, a group of youth netball players were profiled for physical performance measures identified as important to the game demands of netball (Chapter 3). Differences in anthropometry, balance, speed, agility, lower body power and core strength between playing positions and grades were investigated. Differences in physical performance were found between grades and playing positions with grade one players demonstrating better physical capability than lower grade players. Grade one players performed better on: 1) vertical and horizontal jump, 2) speed, 3) change of direction, 4) dynamic stability, and 5) core strength. Differences in playing positions showed circle players jumped further (horizontal), and non-circle players jumped higher (vertical). Non-circle players were also faster in straight line speed and when changing direction. Additionally, circle players were found to be taller than non-circle players. This information on physical performance and anthropometric differences between youth netball players of different playing grades and playing positions could be useful for position-specific training to help develop the capabilities needed for game-play. Recommendations have been provided for position specific training. Including a programme incorporating speed, change of direction ability and plyometrics for non-circle positions and a focus on developing horizontal force production for circle positions. This information also provides preliminary evidence that may also be useful for talent identification.

To understand the effect of the NetballSmart Dynamic Warm-up on performance, a seven-week intervention programme was conducted using a cluster-randomised controlled trial design (Chapter 4). Little was known on the effect of a neuromuscular warm-up on modifiable factors in youth female netball players, therefore the same physical performance measures used in the profile study (Chapter 3) were used in the intervention study. The NetballSmart Dynamic Warm-up was shown to improve prone hold and vertical jump performance, compared to a traditional netball warm-up. This study provided preliminary evidence that some physical performance measures can be improved with the neuromuscular warm-up and resulted in the recommendation that the warm-up be included in regular netball training. It also determined initial evidence that can be provided to coaches that the warm-up can improve physical performance measures. Comparatively, a sub-group study investigating the effect of the NetballSmart Dynamic Warm-up on isokinetic strength of youth female netball players showed no effect (Chapter 5). Isokinetic dynamometry was used to assess concentric and eccentric peak torque measures of the right leg during seated knee flexion and extension at 60^{o}/s. Even though strength is considered a modifiable factor linked to performance and injury, there were no improvements found in knee peak torque, angle of peak torque or the hamstring to quadriceps ratio following the warm-up intervention. It may be that the training stimulus (e.g. exercise type, exercise intensity, exercise frequency) of the programme was not enough to improve maximal strength in female youth netball players. In particular, the absence of progression when delivering the warm-up may have contributed. Furthermore, the effect of neuromuscular programmes in previous studies have been shown to be influenced by compliance, however further exploratory analysis of our data did not reveal any additional benefit of higher compliance. The lack of improvement in strength measures also highlights the importance of “off-court” training. As the warm-up was not effective in improving lower limb strength, additional “off court” training may be needed if strength is to be improved.

Coaches play a key role in the implementation of neuromuscular warm-up programmes in sport. A coach determines what is delivered to players in training. Therefore, achieving the full potential of an injury prevention programme will not be possible if coaches and players do not adopt, correctly implement and maintain the regular use of such programmes. Having investigated the effect of the NetballSmart Dynamic Warm-up, further evaluation was made to consider the level of coach knowledge and their attitudes towards the warm-up and injury prevention in netball. Their experiences with the warm-up were considered to provide further insight to assist the implementation of the programme. A survey of 54 netball coaches revealed poor technique was perceived to be the most common injury risk factor in netball, and almost all coaches believed that a warm-up can reduce injuries. The ankle was correctly reported as the most common lower limb injury. The majority of coaches felt their personal coaching experience was sufficient to be able to coach the warm-up and 81% of coaches reported observing improvements in player ability after using the warm-up. Thematic analysis of the qualitative data identified three dominant themes: 1) the importance of coach education and understanding of injury prevention; 2) long-term player development; and 3) practical implementation of the NetballSmart Dynamic Warm-up. Feedback on the warm-up was encouraging and provided several recommendations for future implementation. It also highlighted that translation of injury prevention programmes from research to real-life contexts is challenging.

Limitations and future research directions

There were some limitations to this research which have been outlined below. Based on these limitations and practical outcomes that resulted from this thesis, some suggestions for future research have also been provided:

- Due to time constraints there were no measures of netball skill or movement quality included in Chapters 3-5. Measures of skill or movement quality (e.g. landing technique) could further assess changes in performance and the effect of the warm-up. Furthermore, additional netball specific tests (i.e. single leg hop, or a change of direction test emphasising rapid acceleration/deceleration) could be included.

- The compliance for the intervention studies was relatively low (Chapters 4-5) and there were some concerns regarding how this was monitored by coaches. As compliance has been shown to influence the outcome of neuromuscular warm-ups, procedures to better report this is recommended for future research.
- There is no standard testing battery that exists between evaluating the effectiveness of neuromuscular warm-ups, making it difficult to compare results of different studies. Consideration of a standardised testing battery is needed.
- Due to the relatively small sample size (Chapters 3-5), changes in performance may not have been large enough to detect.
- The length of the intervention (seven weeks) was limited by the New Zealand school term and thus the availability of players. A longer intervention may have had more of an effect on performance measures due to a longer exposure period. This may have also allowed for the progression of exercises within the warm-up programme (Chapter 3-5).
- Due to the age of the participants in the studies (Chapter 3-5), the participants were untrained which may have created a possible learning effect in some tests. Further test familiarisation in untrained individuals may be beneficial.
- The participants of Chapters 3-5 were from the same chronological age group; however, growth and maturation status were not recorded. This information should be considered in future research involving this age group.
- Due to time constraints, there was no follow-up on coach questionnaires which could have provided further insight to answers and comments given in the survey (Chapter 6). Focus groups with coaches should be considered in the future.
- As coach feedback was the focus in Chapter 6, players were not included in the survey. Including players may provide additional feedback useful for future implementation of the programme.

Practical applications

- A physical profile of youth netball players can be used for training and talent identification.
- Positional differences were found for this playing group. It is recommended that a training programme for non-circle players (WD, C, WA) includes speed, change of direction ability and plyometrics, and for circle playing positions (GK, GD, GA, GS) a training programme should include horizontal force production.

- The NetballSmart Dynamic Warm-up should be included into regular netball training.
- If available, it is recommended that coaches attend a NetballSmart workshop to ensure they are up-to-date on injury and injury prevention in netball and learn how to deliver the warm-up programme.
- Confident and knowledgeable coaches will be able to correctly adjust the warm-up programme to suit their environment and overcome highlighted barriers to the programme.
- It is important that additional “off-court” training is included in the training schedules of youth netball players to help develop strength to enhance their on-court abilities.

Conclusion

This thesis provides several novel perspectives on physical performance and neuromuscular warm-up in youth netball players. To conclude, the thesis has determined a physical performance profile for youth female netball players and preliminary evidence that some physical performance measures can be improved with the NetballSmart Dynamic Warm-up. These findings should assist with promoting the programme to coaches and based on these results, it is recommended that the warm-up be implemented regularly in training. Future research addressing the limitations and building upon the ideas presented in this thesis are needed to further our understanding of warm-up and physical performance in youth female netball players.

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Appendix A: Conference Abstract (Chapter 3)

The following abstract was presented at the 2017 ASCA International Conference on Applied Strength and Conditioning (ASCA):

PERFORMANCE PROFILING OF FEMALE YOUTH NETBALL PLAYERS

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INTRODUCTION: The purpose of this study was to investigate the physical performance characteristics of female youth netball players to provide a physical performance profile and determine if there are differences between level of performance (grade) and/or playing positions (circle versus non-circle) for this group. There is currently limited data on this topic and identifying a performance profile could potentially assist with selection, training, coaching and game development.

METHODS: A total of 102 youth female netball players (mean ±SD: age 13.3 ±0.50 y, height 166.95 ±5.72 cm, body mass 60.94 ±12.80 kg) participated in this study. Measurements included anthropometry (height and body mass), lower body power (vertical and horizontal jump), balance (modified star excursion balance test and time-to-stabilisation), core strength (prone hold), change of direction (T-test), and split sprint times (2, 5, 10, 15, and 20 m). T-tests were used to determine differences in all measures between players in different grades and between players in different positions.

RESULTS: Outcomes of this data showed significant differences in performance measures between playing grades. There were significant ($p<0.05$) differences for playing grade on jump performance, change of direction, and 5 m sprint times. Grade one players had significantly greater horizontal jump performance (mean difference: 15.98 cm & 25.34 cm, $p<0.05$) and significantly lower change of direction times (mean difference: -0.56 s and -1.50 s, $p<0.05$) than grade two and grade four players. Grade one players were also faster over 15 m compared to grade two players (mean difference: -0.11 s, $p<0.05$). Significant differences ($p<0.05$) were found in balance (mean difference: -3.59 composite score) and change of direction (mean difference: 0.68 s) between grade two circle and non-circle playing positions.

DISCUSSION: The results of this study show there were differences in the physical performance capabilities between netball players of this age group playing at different levels. There were also differences between playing positions, providing information that could assist position-specific coaching. These findings have provided general guidelines for a physical performance profile for youth netball players. The results shown in this study could be expected given the game requirements and positional demands of netball, and pre-allocated grades. Similar findings have been found in other studies specific to rugby league, football and volleyball.

PRACTICAL APPLICATIONS: Findings from this study suggest the development of horizontal lower body power, change of direction and speed is important in developing youth netball players in this age group. General guidelines of physical performance measures could also be used for talent identification and selection. Future research involving maturation status, sport-specific skills-based variables and physiological measures should be considered.

Appendix B: The NetballSmart Dynamic Warm-up Summary

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 C: Coach Questionnaire

NetballSmart Dynamic Warm-up: Coaches Questionnaire

Thank you for being a part of this research study. We would like to hear your thoughts and opinions, as a coach, on the NetballSmart Dynamic Warm-up. Please be open and honest and provide as much feedback as possible. These questionnaires are not anonymous, however your privacy will be protected and all information collected will be used for research purposes only. You will not be identifiable in any published findings.

When completing the survey please click on the appropriate box of your selected answer to check the box (click again to un-check the box), or please type in the space provided.

PART A: This section asks you to provide information on your current coaching experience.

Name:

Team/s:

Please state the age group/s you currently coach:

Do you currently play netball? ☐ Yes ☐ No

Number of years coaching experience:

☐ < 2 years ☐ 2-5 years ☐ 5-10 years ☐ > 10years

PART B: This section asks you questions about your attitudes, perceptions and feelings towards injury/injury prevention in netball.

1. What is the most common lower body injury site in netball? *(please select only one answer)*

☐ Knee ☐ Hip ☐ Ankle ☐ Thigh

2. What are common injury risk factors in netball? *(please select all answers that apply)*

☐ Inadequate warm-up
☐ Lack of stretching/flexibility
☐ Lack of fitness
☐ Aggression/ risk taking
☐ Body contact
☐ Poor muscle strength
☐ Poor technique
☐ Player's genetics

3. Which of the above answers *(question 2)* would you rate as the most common injury risk factor in netball? *Please type your answer in the space provided:*

4. Do you believe male and female athletes have the same overall injury risk?

☐ Yes ☐ No

5. Is inadequate warm-up an injury risk factor? ☐ Yes ☐ No
6. Can a warm-up reduce injuries? ☐ Yes ☐ No
7. Who do you believe is primarily responsible for injury prevention? *(please select only one answer)*

☐ Players ☐ Coach ☐ Parents ☐ Medical personal (e.g. physio)

☐ Umpire ☐ School/club ☐ Other: *(please provide detail in space provided*)

8. What strategies do you use with your team/s to prevent injuries?

PART C: Please fill out this section if you were involved in the 7-week intervention study recently conducted by AUT. If not, please continue to PART D.

1. During the study (7 weeks) did your team complete the warm before every game?

☐ Yes ☐ No ☐ Sometimes

2. Post the 7-week intervention study, do you continue to do the warm-up with your team: *(please select all answers that apply)*

☐ Before every training?

☐ Before every game?

☐ Before trainings only?

☐ Before games only?

☐ I have not continued using the warm-up

PART D: This section will ask you about your experience, thoughts and ask for feedback on the NetballSmart Dynamic Warm-up.

How many times a week do you complete the warm-up with your team/s?

☐ 1 ☐ 2 ☐ 3 ☐ > 3

1. Have you observed improvements of physical ability in players as a result of using the warm-up programme? ☐ Yes ☐ No

If yes, please indicate which physical abilities have improved: *(please select all that apply)*

☐ Fitness ☐ Speed ☐ Strength ☐ Movement ☐ Flexibility

☐ Game play ☐ Other: *(please provide detail in space provided)*

2. What are the advantages and disadvantages of the players completing the warm-up?

Advantages
Disadvantages

3. What are the barriers to implementing the warm-up?

☐ Time ☐ Court space ☐ Equipment ☐ Environment ☐ Game play/skills

☐ Programme understanding ☐ Other: *(please provide detail in space provided)*

Please comment on possible suggestions or strategies you use to overcome such barriers:

4. Is the programme applicable to all age groups? ☐ Yes ☐ No
5. Which age groups would you most likely use this warm-up programme with? *(please select all that apply)*

☐ Junior ☐ Y7-8 ☐ Year 9-10 ☐ U17 ☐ U19

☐ Competitive/elite

Please explain why you selected these age groups:

6. Will you use continue to use the warm-up in the future? ☐ Yes ☐ No

Please explain your answer:

7. Do you have any other feedback or comments regarding the NetballSmart Dynamic Warm-up?

PART E: This section will ask you about the implementation of the NetballSmart Dynamic Warm-up.

1. How did you hear about the warm-up?

2. How did you learn the warm-up?

☐ Workshop ☐ Manual ☐ Handouts ☐ Videos ☐ Another coach

☐ Other: *(please provide detail in space provided)*

3. Were you given additional resources to deliver the warm-up?

☐ Yes ☐ No

If yes, please indicate which resources: *(please select all that apply)*

☐ Website ☐ Videos ☐ Handouts ☐ Coach Manual ☐ Equipment

☐ Mentoring ☐ Trainer instruction ☐ Other: *(please provide detail in space provided)*

4. What resources would you like to receive to help you deliver the warm-up?

☐ Website ☐ Videos ☐ Handouts ☐ Coach Manual ☐ Equipment

☐ Mentoring ☐ Trainer instruction ☐ Other: *(please provide detail in space provided)*

5. Was your personal coaching experience sufficient for you to be able to coach the warm-up?

☐ Yes ☐ No ☐ Unsure

6. Did you feel confident delivering the warm-up?

☐ Yes ☐ No ☐ Sometimes ☐ Most times

7. What assistance could further help you in the delivery of the warm-up?

8. Are there any final comments you would like to add to this questionnaire?

THANK YOU FOR COMPLETING THE QUESTIONNAIRE

If you have any questions or comments, please contact:

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18 January 2016

Chris Whatman
Faculty of Health and Environmental Sciences

Dear Chris

Re Ethics Application: **15/458 Effects of a modified Fifa 11+ warm-up programme on physical performance in youth netballers.**

Thank you for providing evidence as requested, which satisfies the points raised by the Auckland University of Technology Ethics Committee (AUTEC).

Your ethics application has been approved for three years until 18 January 2019.

As part of the ethics approval process, you are required to submit the following to AUTEC:

- A brief annual progress report using form EA2, which is available online through http://www.aut.ac.nz/researchethics. When necessary this form may also be used to request an extension of the approval at least one month prior to its expiry on 18 January 2019;
- A brief report on the status of the project using form EA3, which is available online through http://www.aut.ac.nz/researchethics. This report is to be submitted either when the approval expires on 18 January 2019 or on completion of the project.

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

AUTEC grants ethical approval only. If you require management approval from an institution or organisation for your research, then you will need to obtain this.

To enable us to provide you with efficient service, please use the application number and study title in all correspondence with us. If you have any enquiries about this application, or anything else, please do contact us at ethics@aut.ac.nz.

All the very best with your research,

Kate O'Connor
Executive Secretary
Auckland University of Technology Ethics Committee

Participant Information Sheet

Date Information Sheet Produced:

23 November 2015

Project Title

Effects of a modified Fifa 11+ warm-up programme on physical performance in youth netballers

An Invitation

My name is Chloe McKenzie. I am a PhD student at AUT University in Auckland and I am conducting research on netball players. I would like to invite you to be a part of my study.

You and your parents should decide together whether or not to participate. You do not in any way have to participate and may stop being a part of this study at any time. If you agree to be a part of this study, please give your consent by signing and dating the consent form.

What is the purpose of this research?

The purpose of this study is to investigate the effects of a warm-up programme on physical performance measures and how they may relate to possible injury risk in netball.

This study is being done as part of my PhD qualification and the results will be submitted to be published in a scientific journal. It may also be presented at sports science conferences.

How was I identified and why am I being invited to participate in this research?

I contacted the netball coordinators of senior high schools on the North Shore and wider Auckland area asking for their help in finding secondary school teams with players, who are currently fully participating in all trainings and games, and might be interested in participating. If you have been invited for laboratory-based testing at AUT Millennium, this is because your school is very close to AUT Millennium.

What will happen in this research?

During one of your team trainings you, along with your team, will be asked to perform a series of performance tests including:

- Balance: This test will use 8 measuring tapes shaped in a star with one middle point. Balancing on one leg you will stand in the middle and then reach as far as possible with your other foot in the same direction as the measuring tapes; you can lightly touch the floor with your toe. You then have to bring your leg back to the middle without touching the floor or letting your legs touch each other. You will then repeat this test on the other leg.
- Vertical jump: You will stand on a special platform with your hands on your hips and jump as high as you can.
- Speed: You will be asked to run at fast as you can in a straight line. The distance will be measured out by cones.

- Change of direction: You will have to run as fast as you can and change direction in a T-shape pattern. The pattern will be measured out by cones.
- Movement competency screen: You will be asked to perform a squat, lunge and jump while being videoed.

After this testing session you and your team will be asked to perform a specific warm-up, which will be instructed by either me or your coach, before each of your team trainings and games. You will do this programme for 8 weeks. After 8 weeks the same performance tests will be measured again during a team training.

If your school has been selected to be a control group in this study, you will also be asked to perform the same tests above during a team training. However, you will not be required to participate in the 8-week warm-up programme. You will continue to use your normal warm-up routine you usually perform before trainings and games. After 8 weeks you will be asked to perform the same performance tests again. At the conclusion of the study, your team/school will be offered to be educated in the warm-up programme which you can then include in your team trainings and games.

If your school is invited to take part in the laboratory testing, you will follow the same testing as above and then you will be invited to the biomechanics lab at AUT Millennium and asked to do two more tests which are outlined below:

- Movement Competency: You will be asked to perform the same types of movement (squatting, lunges and jumping) as in the movement competency screen above, but this time you will have reflective markers placed on your ankles, knees, hips and shoulders. Three-dimensional video cameras will record your movement and the markers and will help us to understand the way you move. For all jumping movements you will land on a force plate which will record how heavily you land and how high you jump.
- Leg strength: In the lab you will sit in an adjustable chair and have straps placed around your hips and thighs to keep you in place. The chair is connected to a computer and you will be asked to perform some specific movements. The computer will read your level of muscle strength of your legs.

What are the discomforts and risks?

The performance tests and warm-up programme will not be unreasonably difficult. You will experience the discomforts and risks that normally occur from participating in netball training and matches, such as running/sprinting, jumping and landing, squatting, lunging and single leg balance.

How will these discomforts and risks be alleviated?

If you appear likely to injure yourself during the performance tests or warm-up programme through incorrect movement I will correct your technique and/or stop testing. If you have a current injury or for any other reason are concerned you might injure yourself during the performance testing or warm-up programme please let me know.

You may withdraw from the study at any time, including during testing.

What are the benefits?

At the end of the research you will be given a summary of the research findings. This research will help netball coaches and players to better understand how a warm-up programme can enhance performance through decreasing injury risk. For participating in this research, including if you are in a control group, you will go into the draw to win an iPod touch. All names collected from your consent forms will go into a draw, and one name will be drawn randomly to win the prize.

Your participation in this project will also help me to complete my PhD qualification.

What compensation is available for injury or negligence?

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

How will my privacy be protected?

- All information collected will be used for research purposes only.
- Consent forms and contact details will be securely stored on the AUT campus and destroyed after a standard 6 year time period.
- Information collected in this study is not anonymous and complete confidentiality cannot be guaranteed; however, the data from the project will be coded and held confidentially in secure storage under the responsibility of the principal investigator of the study in accordance with the requirements of the New Zealand Privacy Act (1993).
- All reference to participants will be by code number only in terms of the research thesis and publications. Identification information will be stored on a separate file and computer from that containing the actual data.
- Only the investigators will have access to computerised data.

What are the costs of participating in this research?

There is no monetary cost to you to be involved in this research, the only cost is time. All testing sessions will take approximately 1-2 hours.

What opportunity do I have to consider this invitation?

- You may take one week to consider the invitation before responding.
- It is reiterated that your participation in this research is completely voluntary.
- If you require further information about the research topic please feel free to contact me (Chloe McKenzie) or project supervisor, Chris Whatman (details are at the bottom of this information sheet).

How do I agree to participate in this research?

If you would like to participate and are aged 16 or older all you need to do is sign the attached consent form. If you are under 16 years old your legal guardian will need to sign a consent form, while you will sign a slightly different form called an assent form. If you do not have the form you need please call me and I will get one to you.

Will I receive feedback on the results of this research?

Yes, I will write up a brief overview of the results of the research and this will be given to your coach with your consent. If you would also like to receive a summary of the results you can indicate this when you complete the consent form. Please include your email address so the summary can be emailed to you.

What do I do if I have concerns about this research?

Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor, Dr Chris Whatman, chris.whatman@aut.ac.nz, +64 9 921 9999 ext. 7037

Concerns regarding the conduct of the research should be notified to the Executive Secretary of AUTEC, Kate O'Connor, *ethics@aut.ac.nz*, +64 9 921 9999 ext. 6038

Whom do I contact for further information about this research?

Researcher Contact Details:

Chloe McKenzie, School of Sport and Recreation, AUT University. Email: chloe-mckenzie@hotmail.co.nz or phone: +64 21 277 0673

Project Supervisor Contact Details:

Primary Supervisor: Dr Chris Whatman, Faculty of Health and Environmental Sciences, School of Sport and Recreation, AUT University. Email: chris.whatman@aut.ac.nz or phone: +64 9 921 9999 ext. 7037

Additional Supervisor: Dr Matt Brughelli, Sports Performance Research Institute New Zealand, School of Sport and Recreation, AUT University. Email: mbrughelli@aut.ac.nz or phone: +64 9 921 9999 ext. 7025

Thank you for considering participating in this research.

Approved by the Auckland University of Technology Ethics Committee on 18 January 2016, AUTEC Reference number 15/458

Parent/Guardian Consent Form

TE WĀNANGA ARONUI O TĀMAKI MAKAU RAU

Project title:	***Effects of a modified Fifa 11+ warm-up programme on physical performance in youth netballers***
Project Supervisor:	***Dr Chris Whatman and Dr Matt Brughelli***
Researcher:	***Chloe McKenzie***

○ I have read and understood the information provided about this research project in the Information Sheet dated 23 November 2015.

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

○ I understand that I may withdraw my child/children and/or myself or any information that we have provided for this project at any time prior to completion of data collection, without being disadvantaged in any way.

○ I understand that any information my child/I give during this study will be confidential and my child's/my name will not be recorded on any collected data at any time.

○ If my child/children and/or I withdraw, I understand that all relevant information will be destroyed.

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

○ I agree for the results of this research to be shared with netball coaches.

○ I wish to receive a copy of the report from the research (please tick one):
Yes○ No○
Email address: ……………………………………………………………………………………………

Child/children's name/s:…………………………………………………………………………………….

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

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

Parent/Guardian's Contact Details (if appropriate):

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Date:

Approved by the Auckland University of Technology Ethics Committee on 18 January 2016, AUTEC Reference number 15/458

Note: The Participant should retain a copy of this form

TE WĀNANGA ARONUI O TĀMAKI MAKAU RAU

Assent Form

Project title:	***Effects of a modified Fifa 11+ warm-up programme on physical performance in youth netballers***
Project Supervisor:	***Dr Chris Whatman and Dr Matt Brughelli***
Researcher:	***Chloe McKenzie***

- ○ I have read and understood the sheet telling me what will happen in this study and why it is important.
- ○ I have been able to ask questions about the study and have them answered.
- ○ I understand that while the information is being collected, I can stop being part of this study whenever I want and that it is perfectly ok for me to do this.
- ○ I understand that any information I give during this study will not have my name on it and my name will not be recorded on any collected data at any time.
- ○ If I stop being part of the study, I understand that all information about me, including the recordings or any part of them that include me, will be destroyed.
- ○ I understand information from this research will be given to my coaches.
- ○ I agree to take part in this research.

Participant's signature: ....

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

Participant Contact Details (if appropriate):

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Date:

Approved by the Auckland University of Technology Ethics Committee on 18 January 2016, AUTEC Reference number 15/458

Note: The Participant should retain a copy of this form