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Original Research

The effect of the NetballSmart Dynamic Warm-up on physical performance in youth netball players

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ABSTRACT

Objectives: To investigate the efficacy of the NetballSmart Dynamic Warm-up in improving physical performance measures in New Zealand secondary school netball players.
Design: Cluster randomised controlled trial.
Setting: A seven-week intervention study in secondary school netball.
Participants: 81 youth netball players (Intervention group, $n = 45$; Control group, $n = 36$).
Main outcome measures: 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.
Results: Significant improvements in prone hold ($\beta = 20.46$ s; $p = 0.01$) and vertical jump ($\beta = 6.73$ cm; $p = 0.01$) were found in the intervention group compared to the control group, while horizontal jump was found to significantly decrease ($\beta = -9.86$ cm; $p = 0.03$) in comparison to the control group.
Conclusions: 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.

1. Introduction

Netball is a team sport that is common amongst women within the commonwealth countries (Steele, 1990). 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 (McManus, Stevenson, & Finch, 2006; Stuelcken, Greene, Smith, & Vanwanseele, 2013). It requires the performance of explosive anaerobic movements (repeated jumping, turning, sprinting, cutting, acceleration and deceleration) all while catching and passing a ball (Thomas, Comfort, Jones, & Dos' Santos, 2017). 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) (McManus et al., 2006; Stuelcken et al., 2013). 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 (Netball New Zealand, 2017), 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 (Emery, Rose, McAllister, & Meeuwisse, 2007; LaBella et al., 2011; Longo et al., 2012; Olsen, Myklebust, Engebretsen, Holme, & Bahr, 2005; Soligard et al., 2008). A recent systematic review focused on youth concluded there was good evidence neuromuscular warm-up was effective for reducing injury risk (Emery, Roy, Whittaker, Nettel-Aguirre, & van Mechelen, 2015). 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 (Bizzini & Dvorak, 2015; Soligard et al., 2008). Research has demonstrated the effectiveness of this programme in both men and women, reporting 30–50% fewer injuries in players who performed the programme at least twice a week (F-MARC, 2016; Longo et al., 2012; Owoeye, Akinbo, Tella, & Olawale,

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2014; Silvers-Granelli et al., 2015). The majority of the exercises included in the FIFA 11 + are common training exercises; however, they are not routinely used in football training programmes (F-MARC, 2016). 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 technique (F-MARC, 2016). A key element of the programme is using correct technique and proper movement, particularly correct posture and body control and alignment (F-MARC, 2016). 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 (Netball New Zealand, 2018). 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 (Netball New Zealand, 2018). For more details see the manual and instructions freely available on the official Netball New Zealand website (http://www.netballnz.co.nz/Downloads/Assets/41254/1/Dynamic%20Warm-up.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) (Ayala et al., 2017; Kilding, Tunstall, & Kuzmic, 2008; Reis, Rebelo, Krustrup, & Brito, 2013; Zarei et al., 2018). However, several other studies have not reported improvements (Lindblom, Walden, & Hagglund, 2012; Steffen, Bakka, Myklebust, & Bahr, 2008; Vescovi & VanHeest, 2010). Furthermore, there has been no research evaluating the effects 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 effects (e.g. changes in strength and balance (Attenborough et al., 2017; Myer et al., 2009; Opar, Williams, & Shield, 2012; Plisky, Rauh, Kaminski, & Underwood, 2006)) 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 gain 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 (Emery et al., 2015). The importance of greater adherence to a neuromuscular warm-up has been reported previously as a critical point for successful implementation (Soligard et al., 2010; Steffen et al., 2013). Higher adherence to the FIFA 11 + significantly improved functional balance and reduced injury risk (Steffen et al., 2013). Therefore, the purpose of this study was to determine if the NDW could improve physical performance measures in youth netballers.

2. Materials and methods

2.1. 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 Fig. 1 for flow of participants). Participants were allocated to an intervention (INT: $n = 45$, age 13.33 ± 0.48 years;

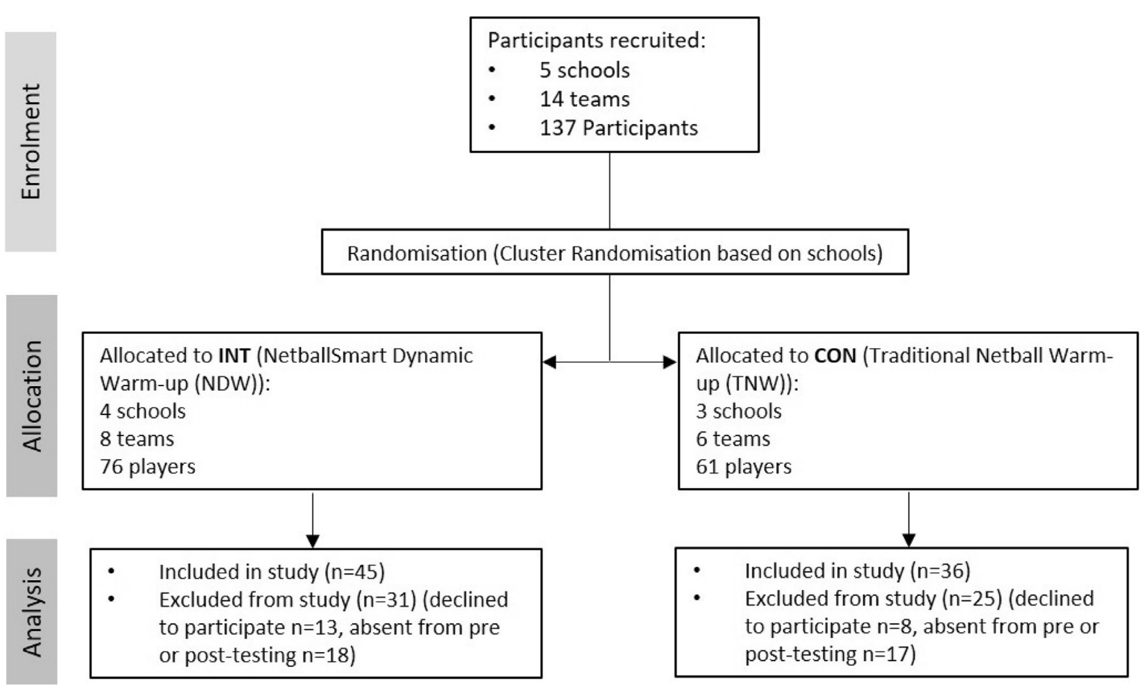

Fig. 1. Flow of participants through the study.

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 6 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.

2.2. Intervention

The INT followed the NDW for seven weeks (3*x* per week), while the CON followed a 'traditional' netball warm-up (TNW). The NDW was delivered to the INT by a qualified trainer 2*x* per week before training, and 1*x* 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 min to complete per session.

2.3. 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, time-to-stabilisation (TTS). All test protocols selected for this study have been used in previous research (Impellizzeri et al., 2013; Kilding et al., 2008; Maulder & Cronin, 2005; Simperingham, Cronin, Pearson, & Ross, 2017). 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 = 0.30–0.91) in a similar group of youth netball players (McKenzie, Whatman, & Brughelli, 2019). Participants performed a 10-min 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 1-min rest between trials). The mean of these three trials was used for analysis.

2.3.1. 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 (Maulder & Cronin, 2005). 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.

2.3.2. Vertical jump

An AMTI portable force plate (Advanced Mechanical Technology, Inc. Watertown, MA) was used to measure vertical jump height. 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 keeping their lower limbs extended during the flight phase of a jump (Impellizzeri et al., 2013). 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 s^{-2} and t = time in air (Moir, 2008).

2.3.3. 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 (Impellizzeri et al., 2013). 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 countermovement jump 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) (Impellizzeri et al., 2013). They were required to hold this position for 10 s. 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 (Tran et al., 2015).

2.3.4. 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 (Kilding et al., 2008). 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.

2.3.5. 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) (Simperingham et al., 2017). 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.

2.3.6. Change of direction

A T-test was used to measure change of direction ability (s) (Impellizzeri et al., 2013). 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.

2.3.7. Balance

A Y-balance test (modified star excursion balance test) was used to measure right single leg balance using a composite score (Filipa, Byrnes, Paterno, Myer, & Hewett, 2010; Impellizzeri et al., 2013). A total of 7 trials was allowed for each direction. The first four trials were practice followed by three recorded trials (Robinson & Gribble, 2008). 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 (Filipa et al., 2010). 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) *x*100) (Filipa et al., 2010).

2.4. Statistical analyses

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) (Hopkins, Marshall, Batterham, & Hanin, 2009). 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.

3. 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 1). In contrast there was reduced performance in 20 m sprint (ES = 0.42, p = 0.001) times. 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 2).

The results of the mixed effects model revealed there were some significant differences between the intervention and control groups (Table 3). 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.

4. Conclusions

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 effects 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 (Ayala et al., 2017; Kilding et al., 2008; Reis et al., 2013; Rössler, Donath, Bizzini, & Faude, 2016).

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 3). 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 1). Similar improvements in prone hold and vertical jump have been found in previous research implementing similar warm-up programmes (Bizzini et al., 2013; Impellizzeri et al., 2013; Kilding et al., 2008; Reis et al., 2013; Zein, Kurniarobbi, & Agung, 2014). Prone hold performance was found to significantly improve in youth futsal players after performing the FIFA 11 + twice per week for four weeks (Zein et al., 2014) and in a group of youth male football players performing the FIFA 11 five days per week for six weeks (Kilding et al., 2008). 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 (Impellizzeri et al., 2013). The implementation of core stability exercises in injury prevention is based on the theory that dysfunction in core musculature contributes to musculoskeletal injury (Huxel Bliven & Anderson, 2013). Therefore, even though the ideal components of an injury prevention programme have not been determined (Huxel Bliven & Anderson, 2013), most multi-faceted injury prevention programmes incorporate exercises that target neuromuscular control of the core through strength, endurance or balance and posture (Kilding et al., 2008; Lindblom

Table 1
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 (7.49–36.73)	0.48 (0.06–0.90)	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 20 m (s)	3.79 ± 0.29	3.91 ± 0.28	0.12 (0.05–0.19)	0.42 (0.01–0.83)	0.001*
Sprint 15 m (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 10 m (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 5 m (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 2 m (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 (1.71–6.55)	0.53 (0.10–0.95)	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 (0.83–3.89)	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 2
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 20 m (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 15 m (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 10 m (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 5 m (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 2 m (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 (1.72–5.41)	0.63 (0.16–1.11)	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 3
Outcomes of the mixed models comparing the effects 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 (11.33–29.60)	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 20 m (s)	0.17 (−0.09 to 0.44)	0.14	1.26	0.21
4	Sprint 15 m (s)	0.03 (−0.04 to 0.10)	0.04	0.72	0.47
5	Sprint 10 m (s)	−0.01 (−0.06 to 0.03)	0.02	−0.63	0.53
6	Sprint 5 m (s)	−0.01 (−0.05 to 0.03)	0.02	−0.61	0.54
7	Sprint 2 m (s)	0.003 (−0.06 to 0.07)	0.03	0.09	0.93
8	Vertical Jump (cm)	6.73 (1.91–11.55)	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 ($p < 0.05$); CI = confidence interval; Coefficient estimates the average difference in the effect between the 2 groups.

et al., 2012; Rössler et al., 2016; Soligard et al., 2008; Vescovi & VanHeest, 2010). According to Leetun, Ireland, Willson, Ballantyne, and Davis (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 (Willardson, 2007), though there is little evidence showing how improvements in core stability can directly enhance sports performance (Hibbs, Thompson, French, Wrigley, & Spears, 2008; Reed, Ford, Myer, & Hewett, 2012). In comparison, core stability has been shown to be important in injury prevention (Leetun et al., 2004). 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 (Netball New Zealand, 2018; Soligard et al., 2008). 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 (Bizzini et al., 2013; Kilding et al., 2008; Zarei et al., 2018), but a number of studies have shown no significant or meaningful change (Impellizzeri et al., 2013; Lindblom et al., 2012; Steffen et al., 2008; Vescovi & VanHeest, 2010). 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 counter-movement jump (CMJ) after performing the FIFA 11 for six weeks in youth male football players (Kilding et al., 2008) 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+ (Reis et al., 2013; Zarei et al., 2018). Furthermore, with the implementation of the FIFA 11+, Bizzini et al. (2013) reported significant improvements in CMJ (5.5%) in male soccer 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 (Lindblom et al., 2012; Steffen et al., 2008). Due to the nature of the game, vertical jumping is a frequent movement performed in netball (Fox, Spittle, Otago, & Saunders, 2013) 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 (Lloyd & Oliver, 2012). Muscular strength has also been reported to be an important factor for correct movement technique (Lloyd & Oliver, 2012). Therefore, as vertical jumping plays an important role in the requisite performance of netball movements (Thomas et al., 2017) 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 (Myer, Ford, Palumbo, & Hewett, 2005). 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, 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 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 (intervention: ES = 0.34, control: ES = 0.63). The star excursion balance test (SEBT), or simplified Y-balance test, is a common measure of balance in comparable studies (Ayala et al., 2017; Bizzini et al., 2013; Impellizzeri et al., 2013; Lindblom et al., 2012; Rössler et al., 2016). Balance is critical in sporting performance and reducing injury risk (Attenborough et al., 2017; Chander & Dabbs, 2016). Movements performed in sport challenge the body's postural control system creating different balance requirements to successfully complete sporting tasks (Chander & Dabbs, 2016). 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 (Netball New Zealand, 2018). 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 (Stuelcken et al., 2013). 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 & low player attendance at training sessions (Lindblom et al., 2012).

Improvements in change of direction of up to 5% (T-test) (Bizzini et al., 2013; Reis et al., 2013) 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 (Rössler et al., 2016). 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 New Zealand 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 (Kilding et al., 2008; Reis et al., 2013; Steffen et al., 2008; Zarei et al., 2018; Zein et al., 2014). 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 (Myer et al., 2005). In comparison to the current study, the training volume was much higher with three 90-min training sessions performed each week (Myer et al., 2005). 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 (Bizzini et al., 2013; Impellizzeri et al., 2013). 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 (Lindblom et al., 2012), there is no standard testing battery that exists between studies investigating the effects 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 (Lindblom et al., 2012; Steffen et al., 2008). These warm-ups, like the NDW, did 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 (Bizzini et al., 2013; Kilding et al., 2008). 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 12-week intervention of FIFA 11+ (Reis et al., 2013). As short sprints are a common movement in netball (Thomas et al., 2017), 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%) (Kilding et al., 2008; Vescovi & VanHeest, 2010). 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.

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.

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 effects of the NDW on performance in youth netball and future research is recommended addressing the methodological issues raised.

Ethical statement

"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."

Conflicts of interest

None.

Ethical approval

This research was approved by the Auckland University of Technology Ethics Committee. As all participants were under 18 years old, written informed assent was obtained from participants and consent from parents/guardians.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ptsp.2019.03.005.

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