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# Effects of wearable resistance during warm-up on physical fitness measures in young female athletes

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## Abstract

The aim of this study was to quantify the training effects of wearing calf-loaded wearable resistance (WR) during a netball specific warm-up in female netball athletes. Twenty-nine high school female netball athletes were matched for change of direction (COD) speed and randomly allocated to either WR training or an unloaded group. Both groups performed the same warm-up two times per week for 6 weeks, with the WR group wearing 1%–1.5% body mass loads on each calf. Pre- and post-training data were collected for 5- and 15-m sprint times, modified 5-0-5 COD splits and total time and single-leg horizontal, lateral and countermovement (CMJ) jump performance. Both groups significantly decreased their 5 m linear sprint times (WRT = −4.41%, effect size [ES] = −1.60; control [CON] = −2.60%, ES = −0.71), while only the WRT significantly decreased their 15 m time (−2.14%, ES = −1.55). There were no significant decreases in 5-0-5 total time for either group, however the WRT group significantly decreased their acceleration (−7.40%, ES = −0.60) and COD split (−9.73%, ES = −1.02). Both groups increased their lateral jump (WRT: 4.60%–6.62%, ES = 0.67–0.96; CON: 5.48%–6.06%, ES = 0.73–0.75), while only the WRT group increased ($p < 0.05$) their horizontal jump (3.57%–4.18%, ES = 0.57–0.67). Given the results, it appears that calf-loaded WR may be an effective method for improving linear speed, aspects of the modified 5-0-5 test and horizontal jump ability in female netball athletes.

**KEYWORDS**
change of direction, linear speed, netball, single-leg jump

## Highlights

- Lower limb wearable resistance (WR) significantly decreases linear sprint time.
- No group decreased their 5-0-5 total time, however the WR group significantly improved their acceleration and change of direction split.
- Both the control and WR group significantly increased their lateral jump, however only the WR group increased their horizontal jump.

## 1 | INTRODUCTION

Netball is a team sport, most common among female athletes, and has one of the largest participation rates within the British Commonwealth (Thomas et al., 2017). Netball is considered a non-contact sport, however it is a physically demanding game, requiring players to have a high level of fitness, strength, power, speed and agility (McKenzie et al., 2019; McManus et al., 2006). Because of these athletic demands, netball players spend a considerable amount of time training in both the gym environment and on the court. As a result, strength and conditioning coaches are required to use resistance training methods which are time efficient, whilst promoting optimum adaptation. The principle of specificity is one of the most utilised training principles in practice, the training an athlete undergoes should closely emulate the activity they wish to improve (Hewson & Hopkins, 1996). Given that netball is a fast paced sport involving high velocity movements such as sprinting, jumping and change of direction (COD) (Thomas et al., 2017; van Gogh et al., 2020), it would seem logical that strength and conditioning programs include exercises that are specific to these game demands. Historically, most traditional strength and conditioning programs take place in gym environments, performing movements that are not specific to which these athletes encounter during matches. Therefore, including resistance training as a part of athletes' court trainings may provide specific physiological adaptations to optimise transference directly to their sport (Bustos et al., 2020).

One potential method for optimising transference, while minimising the time spent in the gym is wearable resistance (WR). The advancement of training technology over the years has seen the use of limb loading via WR compression garments and micro-loads, which have become more common and accessible (Macadam, Cronin, et al., 2019; Macadam, Nuell, et al., 2019; Uthoff et al., 2021). The use of limb loading during sport specific movements provides rotational overload to the limbs, while appearing to have minimal effects on technique during high-speed movements (Macadam et al., 2017; Simperingham et al., 2022; Young, 2006). Previous researchers have shown that lower limb WR loading had significant ($p < 0.05$) acute effects on COD performance (Istvan Rydså & van den Tillaar, 2020), with authors reporting greater COD times with shank loading compared to thigh loading across a range of loading parameters (1%–5% body mass) and splits (time after 45° COD, 90° COD and total time). Ryan et al. (2024) reported that shank-loaded WR (1% body mass per leg) significantly ($p < 0.01$, ES = 0.25) increased total time during a modified 5-0-5 test, as well as significantly increased acceleration ($p < 0.05$, ES = −0.79) and deceleration ($p < 0.01$, ES = −0.47) time splits. Based on the results of these acute studies, it is proposed that shank-loaded WR may provide a potential training stimulus to elicit positive COD performance adaptations over an extended period of time.

One potential use for WR is during an athlete's warm-up. Warm-up programmes are designed to prepare the body for the specific movements encountered during the sport (Bishop, 2003), as well as enhance neuromuscular qualities of athletic performance. Previously Bustos et al. (2020) investigated the effects of warming up with lower-body WR on athletic performance in male soccer players. Athletes performed a warmup with 200–600 g placed on the shank 2–3 times per week for 8 weeks. One key limitation with this study was that the load was not relative to body mass, therefore some athletes may have had a greater relative overload than others. Nonetheless, the authors reported improved 10- and 20-m sprint times in the WR group (10-m = −1.64%, 20-m = −1.23%) compared to the unloaded training group (10-m = 1.38%, 20-m = 0.29%) who got slower (between group effect size [ES] = −1.06 to −0.96, respectively), with 60%–67% of the WR group improving performance above the smallest worthwhile change (SWC), compared to only 19%–37% improving beyond the SWC for the unloaded condition. Both groups had similar improvements in single-leg jump performance (ES = 0.85 and 0.93, respectively; 86.7% and 62.5% > SWC, respectively). The researchers concluded that WR training can elicit practically meaningful improvements in performance, even when it is only implemented into a 15–20 min warm up.

A common warm-up used among netball athletes is the NetballSmart dynamic warm-up, which has been found to improve 5-0-5 COD performance, balance, vertical jump and isometric strength in highschool netball athletes (Belcher et al., 2023; McKenzie et al., 2019). Based on this previous research, it would appear that participating in a structured warm-up routine may elicit improvements in neuromuscular capabilities in netball athletes, however integrating WR may provide potential for further performance gains with no extra training time required. Given the paucity of literature on WR, it is unknown how this training tool and different loading schemes will affect performance in female netball athletes, especially as part of a warm-up, as the current research has been implemented with male athletes (Bustos et al., 2020; Del Vecchio et al., 2018; Feser et al., 2021). It seems that specific netball warm-up programs are useful for enhancing aspects of athletic performance and may be an optimal time to incorporate WR into a training program initially. Additionally, WR is a time-efficient method to induce training effects. Given this information, the aim of this study was to quantify the training effects of adding calf-loaded WR loading to a netball specific warm-up in female netball athletes. It was hypothesised that performance measures such as sprinting, jumping and COD will be greater in the WRT group as compared to the no-load group.

## 2 | METHODS

### 2.1 | Experimental approach to the problem

The effects of a 6-week WR warm-up program on physical performance measures in female netball athletes were analysed using a matched pair randomised control trial design. Testing was completed 1 week prior and post-training to quantify the effectiveness of the WR warm-up program on sprint times, COD ability and vertical, lateral and horizontal single-leg jumping performance. Female high school netball players were matched for COD ability and randomly assigned into a WRT group ($n = 15$) and control (CON) group ($n = 14$).

The WRT and CON groups participated in the same on-court and off-court training sessions and performed the same warm-up. The netball specific warm-up was comprised of low to moderate running, shuffling, jumping, bounding, changes of direction and high intensity acceleration and deceleration drills. The only difference being the WRT group wore compression garments with 500 g–1.2 kg (1%–1.5% body mass) distributed on each calf during the on-court warm-up two times per week.

## 2.2 | Subjects

A priori power analysis was conducted using G*Power 3.1.9.7 to determine the required sample size for a repeated measures ANOVA with two groups (WR vs. control) and two time points (baseline and after 6 week). The analysis assumed a correlation of 0.7 among repeated measures, an effect size of 0.25, alpha level of 0.05 and desired power of 0.80, resulting in a minimum total sample size of twenty-two. Thirty-two high school premier netball players aged 15–18 years volunteered to participate in this study. Subjects were classified as tier 2 athletes as described by McKay et al. (2021). Subjects were matched for COD ability and randomly allocated to either a WRT ($n = 15$, mean ± SD: age: 15.8 ± 0.68; BM [kgs]: 66.85 ± 10.92; height [cm]: 170.06 ± 4.10) or an unloaded CON group ($n = 14$, mean ± SD: age: 16.14 ± 0.95; BM [kgs]: 64.66 ± 10.88; height [cm]: 170.73 ± 7.92). Subjects were included in this research if they were female between the ages of 15–18 years, played high school netball at a premier level and free of any medical issues or injuries that may have affected their participation or performance. Subjects were excluded from this study if they were injured or failed to adhere to the training program with above 80% attendance. Two subjects became injured during the 6-week period outside of the training sessions and one withdrew due to personal reasons, and therefore were removed from the study. A total of 29 athletes completed the 6-week training program. All subjects provided their written and oral consent, or assent, before participating in this study, and where appropriate, subject's guardians provided written consent as well. All research was approved by the Universities Research Ethics Committee, in accordance with the Declaration of Helsinki (23/25).

## 2.3 | Procedures

Testing was conducted one-week prior to the commencement of the program (baseline) and one-week post completion of the program. Testing was conducted at the same time of day, on the same wooden gym floor. The subjects were instructed to wear the same footwear for each testing and training session. Subjects were asked to refrain from any strenuous exercise 24 h prior to testing sessions. On both testing occasions, subjects performed a standardised warm-up consisting of progressive sprinting, dynamic stretching of the lower limbs, COD drills and bilateral and unilateral jumps. Each testing session was used to determine each subjects 5- and 15-m sprint times, multidirectional jump ability and COD ability. Subjects performed three trials for each performance test and were provided with approximately 2 min of rest between trials.

### 2.3.1 | Linear sprint ability

A 15-m sprint was used to test linear sprint ability. VALD smart speed timing gates (VALD Performance) were placed at 0 m (start), 5 and 15 m. The start line was placed 0.5 m back from the first timing gate. Timing gates were set at 1 m, in approximate line with centre of mass. Athletes were instructed to begin the test in a two-point stance with their front foot behind the start line, ensuring the same foot was at the front for each trial and testing occasion. Once the timing gates were ready, participants were instructed to begin the sprint when they felt ready and were instructed to keep maximally accelerating past the last timing gate. The distance of 15 m was chosen, as most players (except for the centre position) are restricted to one third (10.16 m) or two thirds (20.33 m) of the court and it has been reported that netball athletes on average spend 1.0–1.6 s sprinting (Davidson & Trewartha, 2008).

### 2.3.2 | Modified 5-0-5 test

For the modified 5-0-5 COD test, a modified set up was used, described by Ryan et al. (2021). The modified set up with additional timing gates can be seen in Figure 1. Athletes began the test 0.5 m behind the first timing gate in a two-point split stance, with their preferred foot forward. They could begin the test whenever they were ready. To ensure each athlete touched the line, the researchers observed each trial. Athletes were instructed to sprint 5 m and touch their foot on the COD line, perform a 180° on a specific leg and sprint back 5 m through the first timing gate. Subjects performed three trials on their preferred leg.

### 2.3.3 | Single-leg horizontal jump

A single-leg horizontal jump test was used to assess lower limb power in the horizontal direction. The subject was instructed to stand on a single leg with the point of the shoe at a marked line. They were then instructed to jump as far forward as possible, with the use of a countermovement and arm swing allowed, landing on two feet to minimise landing impact. The measurement was taken from the marked line to the heel that was closest to the marked line. The subjects performed three jumps on each leg.

### 2.3.4 | Single-leg lateral jump

A single-leg lateral jump, as described by Hewit et al. (2012) was used to assess lower limb power in the lateral direction. The subject was instructed to stand on a single leg with the inside of their foot at the

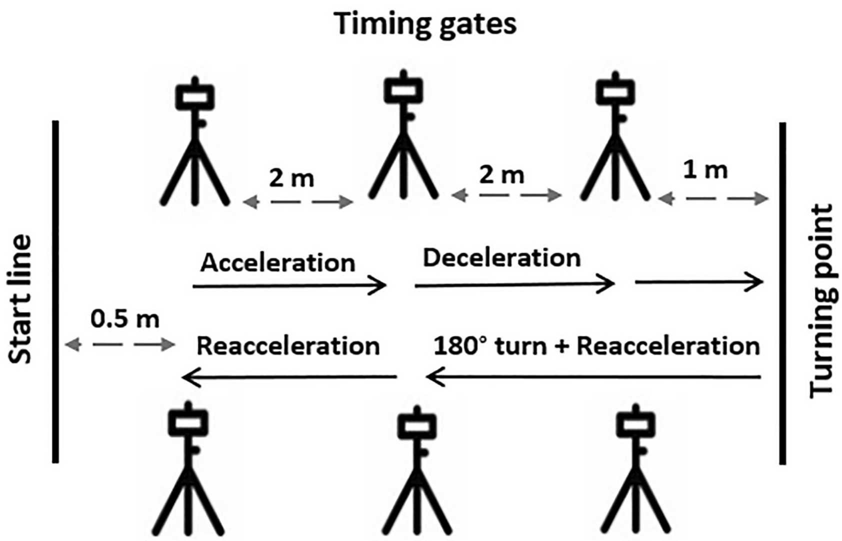


**FIGURE 1** Modified 5-0-5 COD test set up with additional timing gates. COD, change of direction.

marked line. They were then instructed to jump as far as possible to the side, with the use of a countermovement and arm swing allowed, landing on two feet to minimise landing impact. The measurement was taken from the marked line to the outside of the foot closest to the marked line. The subjects performed three jumps on each leg.

#### 2.3.5 | Single-leg vertical jump

The SL vertical jump was performed on ForceDecks Dual force plates (VALD Performance). The subject was instructed to stand as still as possible while their standing weight was measured. Once this was completed, they were told to stand on one leg and were instructed to jump as high as possible with the use of a countermovement and arm swing allowed. The subjects landed on two feet to minimise the landing forces. The subjects performed three jumps on each leg. The average of the three trials was used for analysis.

### 2.4 | Intervention

Both and CON and WRT groups took part in the same training sessions comprising of the same activities and intensities during a 6-week block of the early in-season. The only difference between groups was that the WRT group wore calf sleeves with 1%–1.5% body mass during the 15-min warm-up. The warm-up program consisted of low to moderate running and shuffling movements and dynamic stretches, progressing to high intensity sprinting, fast feet and change of direction movements, with maximal effort jumps. The program has been provided as a Table S1. The WRT program consisted of progressively overloaded WR loads, ranging from 500 g–1.2 kg placed evenly around the athlete's calves (Figure 2). Training was conducted two times per week for 6 weeks, with a total of 12 sessions. An overview of the loading scheme for the WRT group can be observed in Table 1.

### 2.5 | Statistical analyses

The statistical analyses were performed using Microsoft Excel (version 16.0; Microsoft) and SPSS 27.0 (SPSS, Inc.). Data were presented as mean ± standard deviation (SD). Normal distribution of the data was checked using the Shapiro–Wilk statistic. Homogeneity of variance was tested using Levene's test. A two-way repeated measures ANOVA was used to detect within- and between-group effects. The level of significance was set at $p < 0.05$. Mean difference, percentage change and Hedge's g effect sizes were calculated with 95% confidence intervals (CI). Effect sizes were interpreted using the following criteria; trivial effect = ≤0.2, small effect = 0.21–0.49, medium effect = 0.50–0.79 and large effect = ≥0.8 (Cohen, 1998). The smallest worthwhile individual change (SWC = 0.2 × SD) was calculated on the pooled SD of the pre-training session scores for both groups and converted to a percentage for each performance variable, where changes were deemed small (0.2 × SD), moderate (0.6 × SD) or large (1.2 × SD) (Hopkins, 2010).

## 3 | RESULTS

Within- and between-group results for pre- and post-training scores for WRT and CON groups are presented in Tables 2 and 3. The individual responses for each group, relative to the worthwhile changes as a percentage, can be seen in Figures 3–5.

### 3.1 | Linear sprint speed

Both the CON and WRT group had significant ($p \leq 0.01$) within-group improvements in linear acceleration (5 m) (CON: −2.64%, ES = 0.71; WRT: −4.41%, ES = 1.60), however no significant differences occurred between groups ($p = 0.37$, ES = 0.33). In terms of individual responses,

FIGURE 2 Proximal calf loaded wearable resistance.

TABLE 1 Periodised 6-week WR loading strategy for the WR group.

| Session | Load placement | Load |
|---|---|---|
| 1–3 | Proximal | 1% BM |
| 4–6 | Distal | 1% BM |
| 7–9 | Proximal | 1.5% BM |
| 10–12 | Distal | 1.5% BM |

Abbreviation: WR, wearable resistance.

the WRT group had the highest relative number of participants above the SWC (93.33%) compared to the CON group (57.14%).

Both groups improved 15 m linear sprint times (CON: −4.29%, WRT: −2.14%), however only the WRT group had a statistically significant within-group difference, with large training effects noted ($p < 0.01$, ES = 1.55). Once again, no significant differences were observed between groups. The WRT group had the highest relative number of individual responses above the SWC (86.67%) over 15 m compared to the CON group (42.86%).

### 3.2 | Change of direction

The WRT group improved ($p < 0.05$) their split 1 (acceleration) time (−7.40%, ES = 0.60) compared to the CON group (−1.83%, ES = 0.13). No significant differences occurred between groups, however the WRT group had the highest individual response above the SWC (60%), compared to the CON group (35.71%).

Both the WRT and CON group significantly increased their split 2 (deceleration) times ($p < 0.01$) (18.52%, ES = 1.85, and 13.3%, ES = 1.05, respectively), however no significant between group differences occurred. The WRT had the highest individual response above the SWC (93.33%), compared to the CON group (78.57%).

The WRT group decreased ($p < 0.05$) the split 3 (180° turn) time (−9.73%, ES = 1.02), and a significant difference between groups noted ($p = 0.05$, ES = 0.74). The WRT group had 86.66% of athletes above the SWC, while the CON group was only 35.71%. There were no significant within and between group changes in split 4 (reacceleration) or total time.

### 3.3 | Jumping

The results for pre- and post-jump performance can be observed in Table 3. The WRT group increased ($p < 0.05$) horizontal jump distance for both left and right legs (3.57%, ES = 0.57, 4.18% ES = 0.67, respectively), while the CON did not significantly improve performance for either leg ($p > 0.05$). However, no significant between groups differences were detected. The WRT group had the largest individual response rate above the SWC for both left and right leg horizontal jumps (66.66% and 60.00%, respectively) compared to the CON group (28.57% and 42.86%, respectively).

Both groups improved ($p < 0.05$) lateral jump performance for both left and right legs (WRT = 4.60–6.62%, ES = 0.67–0.96, CON = 5.48–6.06%, ES = 0.73–0.75), with no differences observed between the groups ($p > 0.05$). Once again, the WRT group had the

TABLE 2 Descriptive performance testing results, including within-group changes from pre- to post-training and between group differences of the mean changes, for sprint and change of direction variables.

| Test | Group | Pre-test mean ± SD | Post-test mean ± SD | Mean difference (95% CI) | Within-group % Change | Within-group ES (95% CI) | Between-group ES (95% CI) |
|---|---|---|---|---|---|---|---|
| Linear sprint (5 m split) (s) | CON | 1.15 ± 0.05 | 1.12 ± 0.05 | 0.04 (0.01 to 0.06) | −2.64 | −0.71* (−0.13 to −1.26) | 0.33 (−0.39 to 1.04) |
| | WRT | 1.16 ± 0.05 | 1.11 ± 0.04 | 0.05 (0.04 to 0.07) | −4.41 | −1.60* (−0.83 to −2.34) | |
| Linear sprint (15 m split) (s) | CON | 2.86 ± 0.14 | 2.74 ± 0.33 | 0.12 (−0.05 to 0.28) | −4.29 | −0.40 (−0.13 to 0.89) | −0.31 (−1.01 to 0.41) |
| | WRT | 2.84 ± 0.10 | 2.78 ± 0.10 | 0.06 (0.04 to 0.08) | −2.14 | −1.55* (−0.79 to −2.28) | |
| 5-0-5 Split 1 (s) | CON | 0.55 ± 0.05 | 0.54 ± 0.04 | 0.01 (−0.01 to 0.04) | −1.83 | −0.13 (−0.37 to 0.61) | 0.47 (−0.26 to 1.18) |
| | WRT | 0.56 ± 0.05 | 0.52 ± 0.04 | 0.04 (0.00 to 0.07) | −7.40 | −0.60* (−0.06 to −1.12) | |
| 5-0-5 Split 2 (s) | CON | 0.49 ± 0.04 | 0.56 ± 0.04 | −0.08 (−0.11 to −0.04) | 13.3 | 1.05* (0.40 to 1.67) | −0.55 (−1.27 to 0.18) |
| | WRT | 0.49 ± 0.05 | 0.59 ± 0.07 | −0.11 (−0.14 to −0.08) | 18.52 | 1.85* (1.01 to 2.67) | |
| 5-0-5 Split 3 (s) | CON | 1.38 ± 0.08 | 1.37 ± 0.13 | 0.02 (−0.03 to 0.07) | −0.73 | −0.18 (−0.32 to 0.67) | 0.74$^{W}$ (0.00 to 1.47) |
| | WRT | 1.40 ± 0.13 | 1.27 ± 0.13 | 0.12 (0.06 to 0.19) | −9.73 | −1.02* (−0.40 to −1.62) | |
| 5-0-5 Split 4 (s) | CON | 0.47 ± 0.04 | 0.46 ± 0.03 | 0.01 (−0.01 to 0.03) | −2.15 | 0.20 (−0.30 to 0.70) | 0.38 (−0.34 to 1.09) |
| | WRT | 0.46 ± 0.02 | 0.45 ± 0.02 | 0.01 (−0.00 to 0.03) | −2.20 | −0.38 (−0.12 to −0.87) | |
| 5-0-5 Total time (s) | CON | 2.90 ± 0.14 | 2.92 ± 0.13 | −0.02 (−0.08 to 0.04) | 0.69 | −0.18 (−0.68 to 0.32) | 0.40 (−0.32 to 1.11) |
| | WRT | 2.86 ± 0.08 | 2.86 ± 0.09 | −0.01 (−0.04 to 0.03) | 0.00 | −0.07 (−0.56 to 0.43) | |

* Significantly different ($p < 0.05$) from pre-test. W = Significant between group difference in favour of WR group.

TABLE 3 Descriptive performance testing results, including within-group changes from pre- to post-training and between group differences of the mean changes, for jump variables.

| Test | Group | Pre-test mean ± SD | Post-test mean ± SD | Mean difference (95% CI) | Within-group % Change | Within-group ES (95% CI) | Between-group ES (95% CI) |
|---|---|---|---|---|---|---|---|
| Broad jump (left leg) (m) | CON | 1.62 ± 0.17 | 1.65 ± 0.17 | −0.03 (−0.07 to 0.02) | 1.83 | 0.32 (−0.82 to 1.96) | −0.59 (−1.32 to 0.15) |
| | WRT | 1.65 ± 0.16 | 1.71 ± 0.12 | −0.06 (−0.11 to −0.01) | 3.57 | 0.57* (0.04 to 1.08) | |
| Broad jump (right leg) (m) | CON | 1.59 ± 0.21 | 1.61 ± 0.17 | −0.02 (−0.08 to 0.04) | 1.25 | 0.14 (−0.64 to 0.36) | −0.48 (−1.19 to 0.25) |
| | WRT | 1.64 ± 0.06 | 1.71 ± 0.10 | −0.06 (−0.12 to −0.01) | 4.18 | 0.67* (0.09 to 1.24) | |
| Lateral jump (left leg) (m) | CON | 1.44 ± 0.11 | 1.53 ± 0.13 | −0.09 (−0.16 to −0.02) | 6.06 | 0.73* (0.15 to 1.28) | −0.07 (−0.77 to 0.64) |
| | WRT | 1.46 ± 0.16 | 1.56 ± 0.15 | −0.09 (−0.15 to −0.03) | 6.62 | 0.96* (0.36 to 1.55) | |
| Lateral jump (right leg) (m) | CON | 1.42 ± 0.07 | 1.50 ± 0.12 | −0.08 (−0.14 to −0.02) | 5.48 | 0.75* (0.15 to 1.32) | 0.05 (−0.67 to 0.77) |
| | WRT | 1.49 ± 0.15 | 1.56 ± 0.11 | −0.74 (−0.14 to −0.02) | 4.60 | 0.67* (0.12 to 1.20) | |
| Countermovement jump (left leg) (cm) | CON | 10.83 ± 3.83 | 11.79 ± 3.93 | −0.96 (−2.36 to 0.45) | 8.86 | 0.38 (0.15 to 0.91) | −0.02 (−0.76 to 0.72) |
| | WRT | 13.54 ± 3.67 | 14.57 ± 3.08 | −1.03 (−2.38 to 0.31) | 7.61 | 0.40 (0.11 to 0.90) | |
| Countermovement jump (right leg) (cm) | CON | 11.07 ± 4.12 | 11.67 ± 3.64 | −0.59 (−2.10 to 0.91) | 5.42 | −0.22 (−0.74 to 0.30) | 0.25 (−0.48 to 0.97) |
| | WRT | 13.67 ± 3.42 | 13.80 ± 3.92 | −0.13 (−1.21 to 0.96) | 0.95 | −0.06 (−0.54 to 0.42) | |

* Significantly different ($p < 0.05$) from pre-test.

highest individual response rate above the SWC for both left and right legs (73.33%), compared to the CON group (57.14% and 64.29%, respectively), with no significant differences between groups.

Both groups did not significantly increase their single-leg CMJ for either leg ($p > 0.05$). The WRT had slightly higher individual response rates for CMJ improve on left and right leg (60.00% and 33.33%, respectively) compared to the CON group (42.86% and

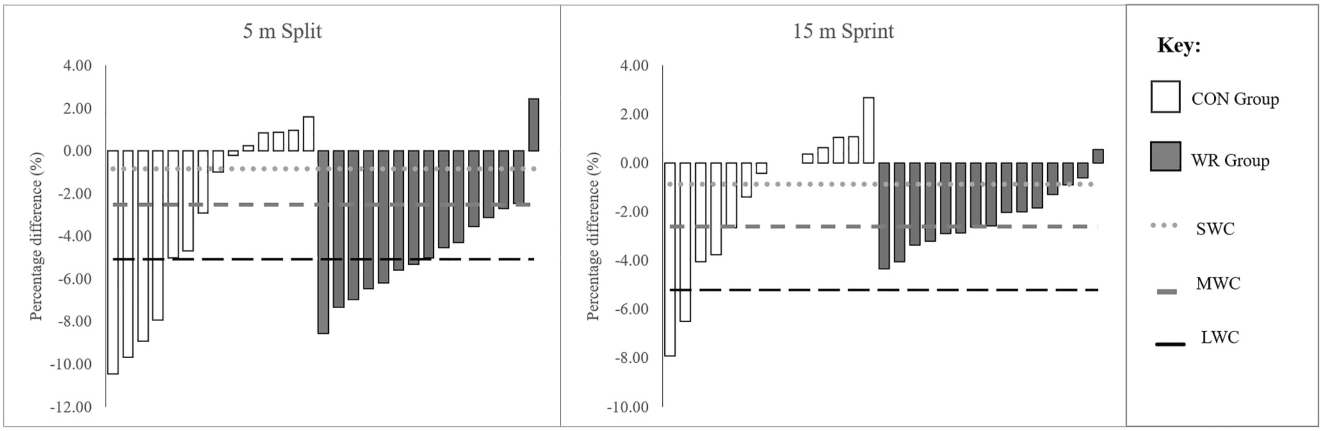


**FIGURE 3** Individual responses for sprint times.

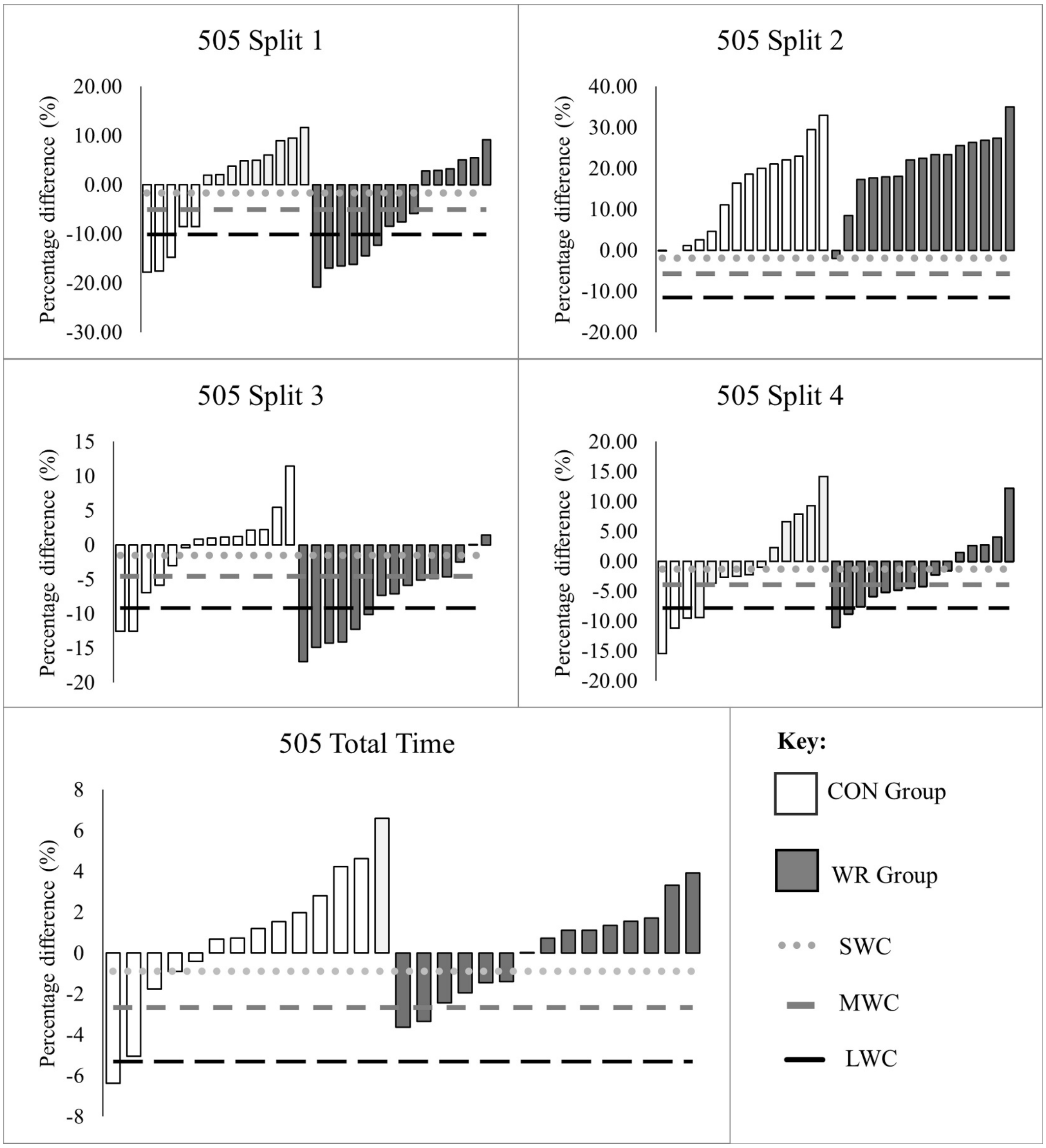


**FIGURE 4** Individual responses for change of direction times.

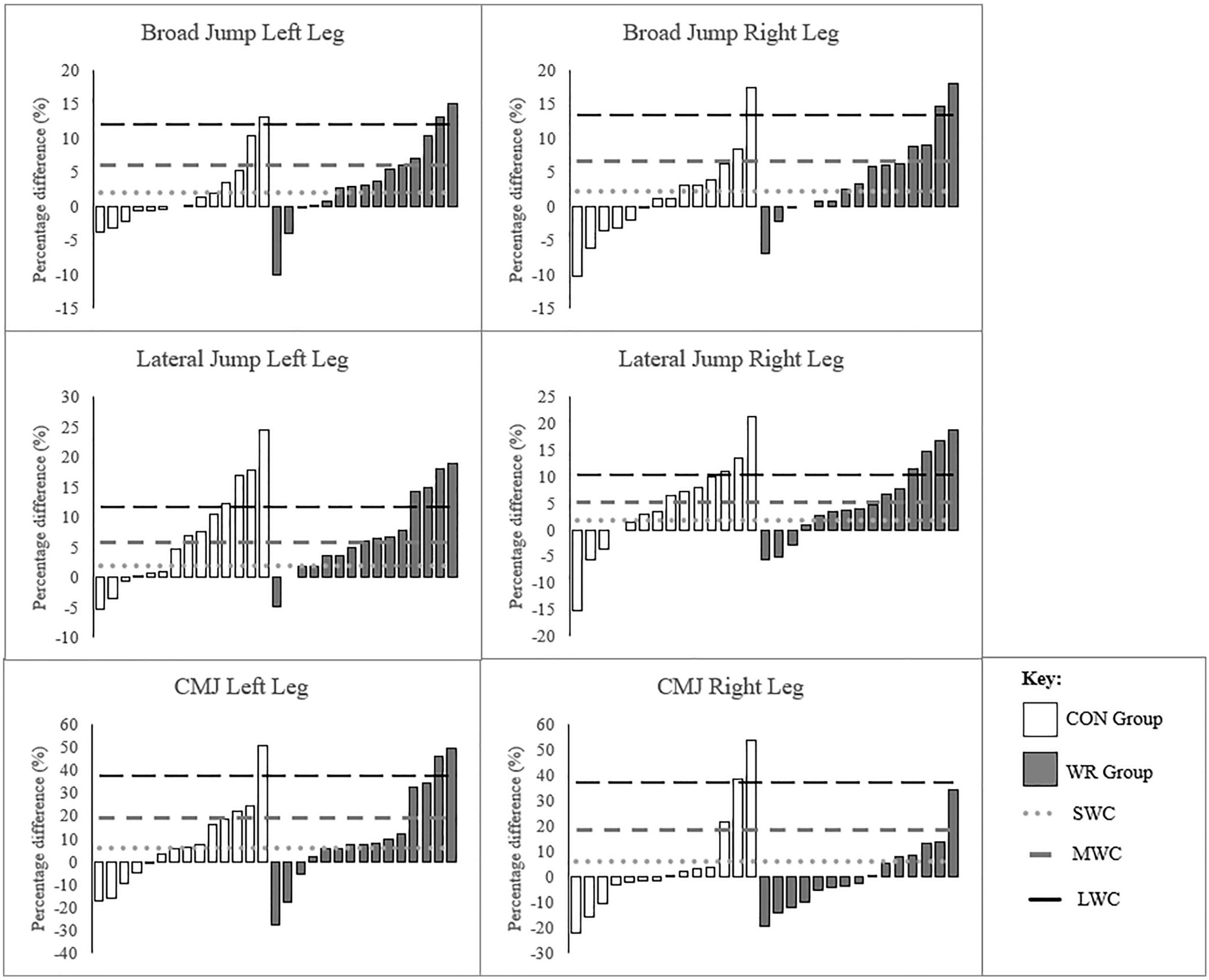


FIGURE 5 Individual responses for single-leg jumps.

21.43%, respectively). There were no significant differences between groups.

## 4 | DISCUSSION

This was the first study to investigate the training effects of WR calf loading in female netball athletes. It was hypothesised that performance changes in sprinting and change of direction (COD) would be greater in the WRT group as compared to the CON group, who performed the same warm-up, without the WR. The main findings of this study were as follows: (1) both groups statistically decreased their 5 m linear sprint split time, however only the WRT group significantly decreased their 15 m time; (2) in terms of COD performance there was no significant decreases in total time during the 5-0-5 test, however the WRT group significantly decreased their acceleration (split 1) and COD (split 3) times; (3) both groups significantly increased their deceleration time (split 2) during the modified 5-0-5 COD test and (4) both groups increased their lateral jump ($p < 0.05$) while only the WRT group increased ($p < 0.05$) their horizontal jump performance.

Though both groups significantly decreased their 5 m split time, the WRT had a large effect (ES = −1.60), while the CON group only had a moderate effect (ES = −0.71). No significant differences were found between groups, however this is likely due to the variation in individual responses. The CON group had three athletes with responses over 8.90%, but only 57.14% of the CON group achieved responses above the SWC. Alternatively, while the highest response rate in the WRT group was 8.57%, all but one athlete (93.33%) achieved improvements greater than the SWC. Though both groups significantly decreased their 5 m split times, integrating WR into a warm-up resulted in significant decreases (−2.14%; ES = −1.55, $p < 0.05$) in 15 m linear sprint times, when performing the warm-up program unloaded (−4.29%, ES = −0.40, $p > 0.05$). Once again, no significant differences were found between groups, however this is likely due to the CON group having two athletes who achieved large worthwhile changes in performance (>6.50%), while collectively only 42.86% of the athletes decreased sprint time below the SWC. Conversely, while no athlete in the WRT group decreased sprint time below the LWC (the largest decrease in time being −4.33%), 86.67% of the group decreased 15 m sprint time below the SWC. These results are similar to the linear sprint results of Bustos et al. (2020), who determined the effect of warming up with calf-loaded WR in male soccer players over an 8-week period. The authors reported significant ($p < 0.05$) improvements in 10 and 20 m linear sprint speed (−1.64%, ES = −0.97 and −1.23% ES = −0.64, respectively) in the WRT group, compared to the CON group (−0.30% and 0.09%). Based on the results of this study, it would seem that the training program, was beneficial for improving initial acceleration from a stationary start, despite the loading condition, however the WRT was superior for developing late-stage acceleration. This is to be expected, as angular kinetic energy is less during the initial acceleration, due to the lower limb velocity, as compared to later stage acceleration where limb velocity is higher, therefore there is greater muscular work due to the angular kinetic energy, that is the work–energy relationship. This finding is important as many coaches and practitioners struggle to fit in all required training, however it appears that athletes can use WR to decrease 15-m sprint time as part of a warm-up rather than having dedicated sprint sessions.

To the authors' knowledge, this is the first study to determine the effectiveness of WR training on COD performance. Previously, Ryan et al. (2024) suggested that training with calf-loaded WR may elicit positive performance adaptations due to the small acute effect on COD performance, specifically 5-0-5 total time. In this study, no significant changes in COD performance were observed, with trivial effects in total 5-0-5 time noted for the WRT and CON groups. Despite no significant decreases in total time for both groups, moderate decreases in the WRT group acceleration split time (−7.40%, split 1) was noted. This is an interesting finding, considering both groups had improvements in linear 5 m sprint times, however only the WRT group improved in the initial acceleration of the COD test, which is ~2 m. There was a moderate yet non-significant between group specific effect, which is likely due to the finding that the CON group had three athletes who achieved LWCs in performance (>−10.13%), while collectively only 35.71% of the athletes had a decrease in split time below the SWC, while the remaining athletes all increased their split times. Conversely, the WRT group had 60% of their athletes decrease their split time below the SWC (<−1.69%). In addition to decreases in the initial acceleration split, the WRT group also had moderate decreases in time during the COD turn and reacceleration out of the turn (−9.73%, split 3). There was a significant difference with moderate effects between groups in favour of the WRT for this split (split 3). Though there was a significant decrease in initial acceleration (split 1), there was no significant decrease in the reacceleration split (split 4) for either group (WRT = −2.20%, ES = 0.38, CON = −2.15%, ES = 0.20). One reason for this may be that an improvement in COD and acceleration out of the turn (split 3) led to disruptions in the reacceleration split (split 4). However, a key limitation for this research was no video footage was taken, therefore it is unclear whether this was the case. Despite this limitation, from the COD results it would seem that while shank-loaded WR did not improve 5-0-5 total time or reacceleration performance, it had a positive effect on improving acceleration and 180° turn ability.

Interestingly, the WRT and CON groups had large increases in split times for the deceleration split (split 2, $p < 0.05$, WRT = 18.52%, CON = 13.3%), however this might be due to the decrease in initial acceleration (split 1). Because of the significantly higher entry speed achieved in split 1 by the WRT group, athletes are required to decelerate either 'harder' or earlier than the pre-testing occasion, in order to perform the 180° COD. Previously, researchers have reported that the biomechanical demands of CODs are 'angle' and 'velocity' dependent (Dos' Santos et al., 2018), which are critical factors that affect the technical execution of directional changes, deceleration and reacceleration requirements. Therefore, by increasing the entry velocity, or in this case, decreasing their split time, into the 180° COD, athletes are increasingly challenged during the deceleration phase to slow their body's momentum down in order to safely execute the turn. These results should be interpreted carefully, because though their split time increased their deceleration performance may have actually improved as they were slowing down from a faster entry speed (i.e. faster split 1). Despite no improvements in total time, it is clear that WR shank loading affected the sub-phases of the 5-0-5 COD test, specifically acceleration and turn/reacceleration, therefore resulting in changes in deceleration strategies.

In terms of jump performance, the WRT group did significantly increase their single-leg horizontal jump performance (right leg: 4.18%, ES = 0.67, left leg: 3.57%, ES = −0.57), which is once again, similar to the results reported by Bustos et al. (2020) (6.25%, ES = 0.77). These results weren't surprising, given the nature of the training and principles of overload and specificity that is, training was primarily in the horizontal direction—force vector specificity. Additionally, it is important to note that shank loaded WR will overload rotational/angular momentum of the thigh and knee, which will likely translate to a horizontal jump compared to a vertical jump. Although no significant differences were identified between the groups, the WRT group had a higher response rate (right leg = 60.0% > SWC, left leg = 66.6% > SWC) compared with the CON group (right leg = 42.8% > SWC, left leg = 28.6% > SWC). Both groups significantly increased their lateral jump, which has been suggested an important factor for 180° COD turning (Chloe Ryan et al., 2023). However, the addition of WR did not enhance lateral jumping performance in this study. As alluded to above, it was no surprise that there were no significant increases in single-leg CMJ height for the WRT (left leg: 7.61%, ES = −0.40, right leg: 0.95, ES = −0.06) or CON group (left leg: 8.86%, ES = −0.38, right leg: 5.42%, ES = −0.22), as the warm-up program was primarily linear, cyclical and ground based, with limited vertical vector training. Once again, similar results were reported by Bustos et al. (2020), where non-significant changes were observed (≤1.66%; $p > 0.05$) in CMJ performance from pre- to post-training for both the CON and WRT group. The reason for the large percentage difference, yet not significant, is likely due to the individual responses seen in Figure 5, the majority of the athletes from both groups either decreased or did not achieve the SWC (6.21%) on the right leg CMJ, however two athletes from the CON group achieved increases above the LWC (37.28%), while one athlete achieved above the MWC (18.64%) in the WRT group. Similar responses were seen for the left leg.

This study had several limitations, firstly no video footage was taken to determine technique changes in the movements and tests. Secondly, only one loading scheme was used (shank loading) progressing loads from 1% to 1.5% body mass each leg. However, it proved difficult to add any more than 1.5% body mass to each calf due to a small surface area and the WR garment slipping if too much mass was added. Thirdly, this research was only performed with high school female netball athletes during a netball warm-up, therefore it is unclear whether different adaptations would be observed for other sports, age groups, as well as dose responses, that is, three versus two sessions per week. Lastly, only one COD test was measured (5-0-5 i.e. 180°). Therefore, different adaptations may have been observed in other COD tests using different entry velocities or COD angles.

## 5 | CONCLUSION

Wearing calf-loaded WR during an on-court warm-up over a 6-week period may be an effective method for improving linear sprint speed, acceleration/reacceleration and turn phases of a modified 5-0-5 test and horizontal jump ability in female netball athletes. These findings may be of particular interest to strength and conditioning coaches working in environments where time is limited. Though many of the findings were not statistically significant between groups, coaches may find the results practically significant given the large effect sizes and individual responses. Given this study was unique and the first to determine the effects of lower limb WR during a netball warm-up, it is difficult to know whether the observed adaptations would be similar for other athletes, sports and levels. Future research should focus on the use of WR training for different frequencies (i.e. 3–4 times per week), different exercises and warm-up protocols and in a range of different sports and levels.

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### CONFLICT OF INTEREST STATEMENT

The authors declare that they have no conflicts of interest.

### DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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## SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.