THE ACUTE AND LONGITUDINAL EFFECTS OF WEARABLE RESISTANCE: TRAINING TO ENHANCE CHANGE OF DIRECTION PERFORMANCE IN FEMALE NETBALL ATHLETES

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ABSTRACT

It is evident that change of direction (COD) ability is important for many field and court sport athletes, and has even been suggested to be one of the key determinants of successful participation in sport. COD is a complex movement and incorporates key qualities associated with athletic performance such as acceleration, deceleration, and directional changes. One common COD manoeuvre is the 180° turn, which is commonly measured via a 5-0-5 COD test. This test traditionally only provides a total time metric, which is of limited value for strength and conditioning practitioners, when it comes to identifying athlete strengths and weaknesses, and creating individualised programs to enhance athletic performance. In terms of training to enhance COD performance, coaches and practitioners have used a range of different specific and non-specific training methods, such as plyometrics, resistance training, sprint training, and COD specific training. In recent years, the use of wearable resistance (WR) has increased in popularity, due to its potential for providing a sport specific overload. This thesis sought to do the following: 1) unpack COD ability and understand the underlying neuromuscular qualities associated with the phases of COD; 2) develop an advanced diagnostic protocol for measuring COD ability, specifically the 180° turn; and, 3) determine the acute and longitudinal effects of a novel training tool (wearable resistance) on 180° COD performance in female athletes.

In Chapters 2 and 3, the lack of data pertaining to the COD ability of female athletes is highlighted, along with a new perspective on understanding COD and how it can be measured via a novel diagnostic protocol. This novel protocol involved the addition of two extra timing gates to the modified 5-0-5 test, therefore providing proxy split times for acceleration, deceleration, 180° turn, and reacceleration out of the turn. In Chapter 4, ten elite level netball athletes volunteered to be a part of the research to determine the reliability of this protocol. It was found that the proposed novel diagnostic protocol was reliable for measuring COD splits and total time in elite level netball athletes (ICCs = 0.57 – 0.97, CVs = 1.1 – 6.6%). Additionally, the strength of association between the splits and total time was investigated to ensure that splits were measuring independent qualities. The greatest shared variance between sub-

phases was 68.9% between deceleration and reacceleration 2 and was the only variable to explain more than 50% of shared variance between sub-phases, suggesting the splits are measuring relatively independent qualities. Further enhancing the diagnostics of this protocol, by including in-sole inertial measurement unit (IMU) technology, was the aim of Chapter 5. The IMU technology was found reliable for providing maximum speed, peak deceleration, and peak acceleration during a modified 5-0-5 COD test (ICCs = 0.57 – 0.96, CVs = 1.8 – 9.5%). Given the acceptable reliability of this advanced diagnostic protocol for a modified 5-0-5 test, it was of interest to determine its utility for coaches with athlete profiling. Chapter 6 focused on determining the insights this novel diagnostic protocol could provide coaches. Of particular interest was to understand what proportion of the test was actually spent in changing direction, if anthropometry and positional differences influenced sub-phase performance and whether a sub-phase analysis could provide better diagnostic information to guide individualisation of programming. It was found that the highest percentage of time was spent during the 180° turn and reacceleration phase (~23%). It appeared that heavier athletes were significantly slower during the modified 5-0-5 test (8.68%), however no differences were identified between taller and shorter players. The use of a sub-phase rank order table provided deeper insights into an individual's COD sub-phase ability, allowing coaches to easily identify individual athletes' strengths and weaknesses in a team sport environment.

A repeated measures design was used in Chapter 7, to determine the acute effects of upper and lower body WR on sub-phase and total time 5-0-5 COD performance. Total time was significantly slower for both WR conditions compared to no load ($p < 0.05$, ES = 0.22 – 0.25). The greatest overload was found for the initial acceleration split (split 1) for both loading conditions ($p < 0.05$, ES = 0.67 – 0.79). Both loading conditions had moderate to large significant effects on peak deceleration (ES = 0.56 – 0.82) and maximum speed (ES = -0.50 - -0.60). It appeared that both upper and lower body WR significantly overloaded an athlete during a modified 5-0-5 test, and therefore may provide a potential training stimulus to elicit positive COD performance adaptations if used over an extended period of time.

Chapter 8 used a matched-paired randomised control design to determine the effectiveness of warming up with lower-limb WR on COD, sprinting and jumping in female netball athletes. Thirty female high-school premier netball athletes were matched for COD speed and randomly allocated to either WR training (WRT) or an unloaded group (CON). Both groups performed the same 15-minute warm-up two times per week, for six weeks. The WR group was wearing shank loaded WR, which progressed throughout the 6-week intervention. Pre- and post-training data were collected for 5- and 15-m linear sprint times, modified 5-0-5 COD splits and total time, and single leg broad, lateral and vertical countermovement jumps. The main findings of this Chapter were; 1) both groups significantly decreased their 5 m linear sprint times (WRT = -4.41%, ES = -1.60; CON = -2.60%, ES = -0.71), while only the WRT significantly decreased their 15 m time (-2.14%, ES = -1.55); 2) 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); and, 3) 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 broad jump (3.57 – 4.18%, ES = 0.57 – 0.67).

Chapter 9 provided a summary of all the key findings from each Chapter and their practical applications for coaches and practitioners. The limitations of this thesis were also explored, followed by future research directions in the use of WR as a tool for developing athleticism.

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LIST OF COMMON ABBREVIATIONS

%: Percentage

Accel: Acceleration

BM: Body mass

CI: Confidence interval

cm: Centimetres

CMJ: Countermovement jump

COD: Change of direction

CON: Control

CV: Coefficient of variation

Decel: Deceleration

DJ: Drop jump

DOM: Dominant leg

e.g.: Example

ES: Effect size

GCT: Ground contact time

GRF: Ground reaction forces

Hz: Hertz

ICC: Intraclass correlation coefficient

i.e.: That is

IMTP: Isometric mid-thigh pull

IMU: Inertial measurement unit

kg: Kilogram

L: Left leg

LWC: Largest worthwhile change

m: Metre

m/s: Metres per second

m/s^2: Metres per second squared

MWC: Moderate worthwhile change

N.B.: Nota bene, “note well”

NDOM: Non-dominant leg

NR: Not reported

PF: Peak force

PHV: Peak height velocity

R^2: Coefficient of determination

r: Correlation coefficient

R: Right leg

ROM: Range of motion

s: seconds

SD: Standard deviation

SSC: Stretch-shorten cycle

SWC: Smallest worthwhile change

WR: Wearable resistance

WRT: Wearable resistance training

yrs: Years of age

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 used artificial intelligence tools or generative artificial intelligence tools (unless it is clearly stated, and referenced, along with the purpose of use), 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.

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Chloe Mihi Cathalina Ryan

CO-AUTHORED PUBLICATIONS

The co-authored publications listed below are a result of the research conducted in the fulfilment of the degree of Doctor of Philosophy.

STUDENT AND SUPERVISOR APPROVALS

By signing you are confirming that the co-author contributions stated in the table) below are accurate.

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The student was the main contributor (90%) of the research and subsequent analysis and interpretation of the research in this thesis. Additionally, the student was the primary contributor (90%)

to the writing of research ethics applications, progress reports and papers, as well as being the main presenter at conferences.

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

Supervisors

Dr Aaron Uthoff (Primary Supervisor)	**Dr Chloe McKenzie (Secondary Supervisor)**
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He rangi tā matawhāiti,
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A person with narrow vision has a restricted horizon; a person with wide vision has plentiful opportunities

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CHAPTER 1 - PREFACE

1.1 Background

Change of direction (COD) is one of the key determinants of successful participation and athletic performance in many field and court sports (196). COD incorporates key qualities associated with athletic performance such as acceleration, deceleration, and directional changes (165). There are several different COD manoeuvres, with 180° COD being one of the most common for many field and court sport athletes (99). The traditional and modified 5-0-5 COD tests are two of the many tests that feature a 180° turn and provide the focus of this thesis. 180° COD requires athletes to decrease their horizontal momentum to zero, rotate their body and plant their foot ahead of the centre of mass to produce horizontal braking and propulsive impulse and reaccelerate again. In order to effectively perform this complex task, an athlete must have proficient linear acceleration and speed, deceleration capability, technique and physical capacity (maximal strength, rapid force production, neuromuscular control and muscle activation) (54, 55, 112, 206, 207). In comparison to other COD tasks such as the 45° cut, the 180° COD is generally categorised by slower entry velocities due to the high biomechanical demands of the task. This is related to the ‘angle-velocity trade-off (55), whereby higher COD angles require slower entry velocities as faster approaches compromise the execution of the directional change.

Sports such as netball, rugby, soccer and hockey are all examples of sports that require good COD ability. Netball is a sport characterised by quick and sharp changes of direction in both attack and defensive actions (75, 208). Though many of the directional changes performed in netball are in response to a stimulus i.e., agility, the use of COD assessments is of importance firstly, to determine the physical qualities of agility performance and secondly additional equipment to provide a standardised stimulus for the assessment of agility may not be feasible for many coaches and practitioners. In order to understand how we can improve COD ability, we first need to understand the different phases of changing direction, and how to measure these phases. This thesis focuses on unpacking COD ability, developing an advanced diagnostic protocol for measuring COD ability and looking at using wearable resistance (WR) as a sports specific training tool for improving COD ability. This thesis has the potential to provide coaches and practitioners with new ways to assess, analyse and improve COD performance in all field and court sports. The following sections outline the current gaps in the literature and highlight the importance of this thesis.

1.1.2 Lack of female representation and elite level athletes

It is evident that COD ability is important among most field and court sports, which are played by both male and female athletes. However, the majority of the current COD researchers have focused on male athletes (62, 115, 174, 219, 222). The lack of female representation makes it difficult for coaches and practitioners to train and programme for female athletes whose sport require COD capability, given the lack of research on assessment and training prescription, as well as the lack of normative data specific to sex and sport. Additionally, it has been identified that there is both a lack of netball athletes and elite level athletes whose COD capability has been investigated. In this thesis, elite athletes were defined as those competing at international and/or national level. Considering it has been reported that COD ability was the most important performance variable for predicting player selection in soccer athletes (83) and American National Football League draft status (146), more information and normative data is needed for elite level athletes. Netball is one of the most popular female sports in the British Commonwealth and often requires athletes to perform rapid COD movements, however, it seems to be underrepresented in the research.

1.1.3 Improving testing diagnostic value

The tests that currently exist for assessing COD performance use total time as the measure of performance. However, these COD tests all have different phases which involve various athletic qualities such as linear acceleration, deceleration, and turning. It has been suggested that an athlete who is fast linearly may still perform well in a COD test, as their sprinting ability could mask any deficiencies in COD ability (165). This concept is supported by several studies, where researchers have found moderate to large correlations ($r = 0.62$-0.93) between linear and COD speed tests (79, 125, 192).

Therefore, the use of total time may not be a true representation of COD ability and certainly not the different components that make-up COD.

Currently, the use of timing gates is the most common method for recording 5-0-5 COD data (190, 219) and has been shown to be reliable (219, 222). Total time is the only value given for these tests, however it is evident that the 5-0-5 COD test requires athletes to possess many different athletic qualities (165). Given this information, there was a need for the 5-0-5 COD test to be further advanced to increase the diagnostic value of this test. This was done through the addition of extra timing gates during the test. The addition of extra timing gates was recently been investigated by Forster and colleagues (73) during the pro-agility test, however reliability was shown to be poor for several of the sub-phases. Similarly, reliability testing was needed for the modified 5-0-5 test to determine if this test could reliably measure certain sub-phases e.g. acceleration, deceleration, COD and reacceleration. Furthermore, Forster and colleagues (73) only used male participants, therefore no research on advancing COD testing has been performed with female athletes. By adding extra timing gates to the modified 5-0-5 COD test, five different split times were produced, giving insight into an athletes' accelerative, decelerative, 180° turn and reacceleration ability. Additionally, these deeper insights could provide information on an athlete's COD strategies, deceleration deficits, acceleration deficits and turning abilities to better inform individualised training programmes.

In addition to the timing gates, 5-0-5 COD performance may be assessed using accelerometers embedded in the shoes using equipment such as Plantiga foot pods (inertial sensor insoles, with AI driven software) (Plantiga Technologies, Vancouver, Canada). This new technology can give insight into the speeds, accelerations and decelerations attained during the 5-0-5 test and offers a new way to analyse sporting performance. Previously, researchers have used shoe mounted accelerometers to measure step kinematics and movement characteristics during walking (42, 171) and running (76, 81). Because Plantiga technology is relatively new technology and are inertial sensor insoles that are placed within the shoe, rather than being mounted atop the shoe, research is needed to determine the reliability and utility of this movement assessment tool. Additionally, to the authors knowledge, there is limited research that has used inertial sensor technology to measure and quantify COD performance (3). Therefore, as part of this project, it was of interest to use this inertial sensor technology during a modified 5-0-5 COD test to explore whether foot pod technology could add diagnostic value. This technology has the potential to identify asymmetries that occur during COD movements, as well as peak accelerations and decelerations experienced during movement tasks. These are all factors that can influence player performance, as well as a potential tool to identify players at risk of injury.

1.1.4 Improving COD performance and wearable resistance

Researchers have found links between different types of non-specific and specific training methods for enhancing COD performance (37, 169). Non-specific training methods tend to be gym-based, vertically orientated movements, allowing for the development of neuromuscular qualities that have been linked to 180° COD performance, such as sufficient eccentric, concentric and reactive strength (183). A considerable number of researchers focused on non-specific training methods such as traditional resistance training (16, 115, 156) and plyometric training (8, 23, 168), which have had positive effects on 180° COD performance, however it has been speculated that specific COD training may yield superior improvements in performance (51). This assumption is based on the proposed enhancements in technical skills and contraction-movement specific training.

Specificity of training is essential for optimising transference of training to sports performance (34, 74). Specific training methods refer to movements and training that resemble the biomechanics of movements performed during specific sporting tasks. COD is a complex movement that requires numerous neuromuscular capabilities, and therefore it is possible that training in a more sports specific way may be of better benefit than non-specific training methods (35). To the authors knowledge, there is limited research (20, 23, 53) on specific training methods used for 5-0-5 and 180° COD training, and all the current research has used male participants. Additionally, Dos'Santos and colleagues (59) have also reported that COD speed and technique modification during 180° turning performance, resulted in meaningful ($p < 0.05$) improvements in completion time, horizontal propulsive forces in shorter ground contact times, ability to apply and orientate penultimate foot contact braking force and final foot contact propulsive force more horizontally. Additionally, the authors saw improvements in pelvis rotation, smaller final foot contact knee flexion range of motion and greater velocity reduction at the penultimate foot contact. Though technique modification was not the focus of this PhD, the findings of this research highlight the potential for specific training to result in COD improvements.

In recent years, the use of WR, where micro-loads (50-300 g) are attached to compression garments, has enabled athletes to overload movement in a more sport specific manner. It can be applied to the torso (see Figure 1.1 A) to provide a vertical overload, that reduces the rise and fall of the centre of mass displacement during gait, thereby reducing step length (131). With withdrawal of the torso loading, it has been proposed that step length increases (131). Limb loading (see Figure 1.1 B-C) on the other hand, provides a rotational overload, in terms of increasing the rotational inertia of the lower and upper limbs. As a results of the added mass to the limbs, velocity of the limbs is reduced, which in turn affects step frequency (131). Though theoretically both vest and limb loading could enhance COD performance, limb loading was chosen given the spatial constraints of the 5-0-5 test, and the step frequency focus. Given torso loading is best for providing vertical overload, it has been suggested to be the most effective for maximum velocity sprinting and vertical jumping tasks (131). Additionally, as horizontal force production is important for 5-0-5 COD performance it was hypothesised that the limb loading would provide a more specific overload i.e., rotational horizontal overload compared to the vertical vest loading.

Figure 1.1: Different wearable resistance loading. A = torso loading, B= forearm loading, C = shank loading

Limb loading is associated with high levels of activity specific muscular work (128, 130). Important in progressing the overload during limb loading, is understanding the concept of rotational inertia which is the product of mass x radius^2 ($I = mr^2$). Where the load is placed in relation to the axis of rotation is important, as the radius (i.e., distance from the axis of rotation), has an exponential effect on the magnitude of the overload. For example, Dolcetti et al., (52) showed that 400 gm placed mid-femur versus distal femur, resulted in substantial increases (4.73% vs 12.1%) in rotational inertia. So, in the case of the distal loading, there was ~12% more muscular effort required to accelerate and decelerate the thigh for every step taken. Given this information, a shank loading protocol was chosen for this research as compared to thigh, due to the additional overload at the hip joint. Additionally, the load on the shank is also providing overload at two joints (knee and hip). Finally, the same relative load at the shank compared to the thigh would provide greater muscular work due to the work-energy relationship, that is the amount of mechanical work performed by a muscle group is determined by the mechanical energy associated with the movement (mechanical work = kinetic energy [KE] = $1/2mv^2$). In this equation, the effects of velocity are exponential, limb velocity having a larger effect on the kinetic energy compared to the mass, which is halved i.e., the speed of the movement is more influential in determining mechanical work than the mass used. Given this information, shank loading was chosen as one of the overloads to explore in this thesis. The second overload explored is forearm loading. In COD, the arms play an important role in the rotation of the body and helping shift an athlete's momentum in a new direction (30), therefore it was thought that overloading the arms may provide a movement specific training stimulus to improve COD performance. Similar to the lower limb loading, concepts of rotational inertia and work = energy relationship, informed the decision making around the choice of lower arm loading, to overload the shoulder and arm musculature. Specifically, the biarticular loading, the greater distance between the lower arm load and the shoulder axis of rotation, and the greater lower arm limb velocity, meant that such loading would provide a greater overall stimulus.

With regards to the research investigating the acute effects of limb loaded WR on linear sprint performance during the acceleration and maximum velocity stage (70, 128, 132), authors have reported acute increases in sprint time for both types of loading. In addition to these acute findings, several research groups have reported positive adaptations to sprint performance after a period of training using limb loaded WR (33, 69). While an array of research has been done on linear sprint performance, there is a paucity of research on the effects of limb loaded WR on COD performance (186). Rydså and van den Tillaar (186) concluded that lower limb WR loading with different loads (shank and thigh loading with various loads of 1-5% body mass) had an acute negative effect on COD performance in male football players, that is, the addition of WR loading provided an overload during COD performance, resulting in significantly slower 90° and 45° split times. It was reported that distal placement (i.e., shank) compared to proximal (i.e., thigh) with similar body mass (BM) load, had a larger acute negative effect on COD performance, particularly in 90° turns compared with 45° turns. This is to be expected due to the increase moment of inertia, explained previously.

Given the preceding information, and knowledge gaps around the use of WR for training COD, the focus of the thesis was to determine the effects of upper and lower limb loading on COD performance. Furthermore, since the research in this area thus far has focussed on the training of males, the effect of WR loading on female athletes is unknown. It is yet to be determined whether female athletes would adapt differently to the same WR loading strategies and training protocols. Since female athletes have different physiology and anthropometry (muscle mass, fat distribution, muscle architecture etc.,) compared to male athletes (1, 108, 114, 121) it is assumed that male results cannot be generalised to their female counterparts and females may need different loading strategies to elicit the same or similar adaptations to males.

1.2 Thesis rationale

Firstly, this research provides coaches and practitioners with normative COD data on not only female athletes, but elite female athletes. Secondly, a range of new perspectives on COD, specifically the 5-0-5 COD test and its sub-phases (i.e., acceleration, deceleration, 180° turn and reacceleration) are developed. It is important for coaches and athletes to understand that COD is a complex skill and being measured through a single time does not provide the granular information needed to advance assessment and training prescription. Sports such as netball, rugby and hockey are all examples of sports that require COD ability. In order to understand how COD ability can be improved, the different phases of changing direction, and how to measure these phases needs to be understood. COD ability requires various neuromuscular capabilities such as, concentric, eccentric, and reactive strength, as well as several other factors such as technique and optimised anthropometry (196). This is important information for coaches to know, as it will determine how they assess and programme for COD. The diagnostic advancement of the modified 5-0-5 COD test will provide coaches with a more comprehensive understanding of the sub-phases involved in COD performance. Having knowledge of athlete performance over the different sub-phases provides coaches and practitioners with the information to improve programming and individualise an athlete's exercise prescription. For example, this advanced COD test could identify that an athlete has poor reacceleration after performing a COD movement, therefore the focus of their training would be to perform more dynamic strength training with relatively large ranges of motion, to improve their reaccelerative ability out of the turn. As well as advancing the tests used to measure COD performance, this thesis will provide insight into a potential new and sport specific way to train COD movements. The investigation into the acute and longitudinal effects of WR limb loading strategies may lead to the development of new and novel sport specific training method for sub-phases of COD and overall COD performance in athletes.

1.3 Purpose and research questions

This PhD was conducted with the purpose of answering the overarching question: “Can wearable resistance improve change of direction performance in female netball athletes?”. A series of reviews and experimental studies were completed to answer the following research questions and ultimately the overarching question.

1. What normative and reliability data currently exists for the traditional and modified 5-0-5 COD test?
2. What athletic qualities are required in each sub-phase of the 5-0-5 COD test, and can the measurement of 5-0-5 COD performance be improved?
3. Can the diagnostic value of the modified 5-0-5 COD test be advanced to provide greater diagnostic information? This will include:

   a. Are the modified 5-0-5 sub-phases and total time reliable when measured using an advanced diagnostic protocol with timing lights?

   b. Can IMU foot-pods reliably measure modified 5-0-5 COD performance in elite netball athletes?
4. Does an advanced diagnostic protocol provide coaches with greater insight into athlete performance and individualisation of programming?
5. What are the acute effects of different WR loading strategies on 5-0-5 COD performance?
6. What are the chronic effects of lower limb WR on 5-0-5 COD performance?

1.4 Research design

Two reviews and five experimental studies were used to answer the thesis research questions:

1. A normative and reliability analysis using a systematic approach was undertaken to examine the current information on 5-0-5 performance, focusing on the sex, sport, level and age of the athletes, as well as the reliability of the technology currently used to measure 5-0-5 performance.
2. A narrative review was undertaken to determine the key qualities associated with 5-0-5 COD performance, and a new COD deterministic model was proposed, along with an advanced diagnostic protocol.
3. A repeated measures design was used to establish the reliability of an advanced diagnostic protocol for the modified 5-0-5 test, using:
    a. Dual beam timing lights
    b. Inertial measurement units (foot pod technology)
4. Data collected with the advanced diagnostic protocol was used to profile elite netball athletes COD abilities and identify areas of strength and weakness.
5. A repeated measures design was used to establish the acute effects of upper and lower body WR on the 5-0-5 COD test.
6. A match-paired randomised comparative trial was used to examine the chronic effects of lower body WR on sprinting, jumping and COD performance in female netball athletes.

1.5 Originality of the thesis

Within the current literature, there is very little research that exists on COD training in female athletes, and no research available on:

1. Normative data and reliability of various technologies used during the traditional and modified 5-0-5 COD test.
2. Key qualities associated with 5-0-5 COD performance and new perspectives on measuring and programming for 5-0-5 COD ability.
3. The reliability of a novel and new diagnostic protocol for measuring 5-0-5 performance.

4. The ability for an advanced diagnostic protocol to identify strengths and weaknesses in 5-0-5 COD performance.
5. The acute effects of different WR loading strategies on 5-0-5 performance in female athletes.
6. The training effects of WR on COD performance, specifically 5-0-5 COD.

1.6 Structure of the thesis

Chapters 2 through to 8 were written in the format of published journal articles to fulfil the Pathway Two thesis requirements at Auckland University of Technology. These chapters have been submitted as stand-alone publications to peer-reviewed journals within the area of exercise science and applied strength and conditioning. The reference and journal where the piece of work was submitted is detailed at the beginning of each chapter along with a prelude detailing how each chapter links and subsequently build upon each other to ensure the thesis is a unified and cohesive piece of work. This thesis is divided into nine chapters consisting of four thematic sections designed to answer the over-arching question. A schematic structure of the thesis is outlined in Figure 1.2.

The first section includes the introduction and two literature reviews. The introductory chapter provides the rationale for the research, the originality, and the structure of the PhD, while introducing the key concepts discussed throughout the PhD (e.g., importance of COD in field and court sport athletes, lack of research around female athletes and the potential for WR to be used to enhance performance). Chapter 2 is a normative and reliability analysis review, detailing the current research using the 5-0-5 COD test (both traditional and modified) across a variety of sports, levels and ages in both male and female athletes. Additionally, the most common and reliable tools used to measure COD performance were discussed. In Chapter 3 a new perspective on measuring and quantifying COD performance is introduced, and the key qualities associated with excellent COD performance proposed.

Section two consists of acute experimental chapters. Chapters 4 and 5 focused on the reliability of an advanced diagnostic method for measuring 5-0-5 COD performance, which was proposed in Chapter

3. Timing gates are used in Chapter 4, which are the most common piece of technology used amongst coaches and practitioners. This chapter provides a way to gain additional insight with the use of three sets of timing gates rather than one. Inertial measurement units (IMU) located in the shoes are used in Chapter 5, which is a novel piece of technology and is not commonly available to coaches and practitioners. This research was performed with elite female netball athletes. The relationship between the sub-phases and IMU variables provided by the advanced diagnostic protocol were also explored. Chapter 6 focused on profiling COD ability using the results from the advanced timing light protocol. In this chapter it is proposed that the additional information provided can help coaches and practitioners identify strengths and weaknesses for their athletes and program accordingly.

Section three focuses on the acute and longitudinal effects of WR on COD performance in female netball athletes. The effects of different WR loading strategies on COD performance via a repeated measures design are explored in Chapter 7. Athletes performed the modified 5-0-5 COD test with an advanced diagnostic protocol (additional timing gates and IMU in-soles) under three different conditions (no load, shank load or forearm load). Finally, Chapter 8 focuses on the training effects of shank loaded WR in premier high-school female netball athletes. This research used a match-paired randomised control trial to compare the training effects of 6-weeks of progressively overloaded WR training during a netball warm-up, on speed, lower-body power and COD performance. Overload was achieved by increasing the load (as a percentage of BM), and the distance of the load from the axis of rotation.

The final section of this thesis consists of Chapter 9, which provides an overall summary, along with practical applications, limitations and future research directions.

Can wearable resistance improve change of direction performance in female netball athletes?

Section One: Theory and review of the current literature around 5-0-5 COD performance

Chapter 1: Introduction/Preface

Chapter 2: Systematic review – "Traditional and modified 5-0-5 change of direction test unpacked: normative and reliability analysis"
Published in *Strength and Conditioning Journal*

Chapter 3: Narrative review – "New perspectives of the modified 5-0-5 COD test"
Published in *Strength and Conditioning Journal*

Section Two: Advancing the diagnostics of the 5-0-5 COD test

Chapter 4: Reliability experimental study - "Sub-phase analysis of the modified 5-0-5 test for better change of direction diagnostics"
Published in *The Journal of Sport and Exercise Science*

Chapter 5: Reliability experimental study (within-session) – "Inertial measurement unit analysis for providing greater diagnostic value during the modified 5-0-5 change of direction test"
Published in *The Journal of Sport and Exercise Science*

Chapter 6: Experimental study – "Profiling change of direction ability using a sub-phase 5-0-5 analysis"
Published in the *International Journal of Strength and Conditioning*

Section Three: Acute and chronic (6-weeks) effects of WR on COD performance

Chapter 7: Experimental study - "The acute effect of wearable resistance placement on change of direction performance in elite netball players"
Published in *European Journal of Sport Science*

Chapter 8: Experimental study – "Effects of warming up with lower-body wearable resistance on change of direction, linear speed, and leg power"
Under review at *European Journal of Sport Science*

Section Four: Conclusions, practical applications and future research directions

Chapter 9: Summary, practical applications, limitations, and future research directions

Figure 1.2: Structure of thesis.

CHAPTER 2 - TRADTIONAL AND MODIFIED 5-0-5 CHANGE OF DIRECTION TEST: NORMATIVE AND RELIABILITY ANALYSIS

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

Reference:

Ryan, C., Uthoff, A., McKenzie, C., & Cronin, J. (2022). Traditional and Modified 5-0-5 Change of Direction Test: Normative and Reliability Analysis. *Strength and Conditioning Journal*, *44*(4), 22-37.

2.0 Prelude

In the previous chapter, it was identified that COD ability is an important performance factor in many field and court sports and can be used for player selection. The purpose of this chapter was to collate the available literature on normative data and reliability pertaining to the 5-0-5 COD test and categorize this information based on sport, sex and level, so performance comparisons could be made. Additionally, this review aimed to identify current gaps within the 5-0-5 COD literature and provide justification for the research direction of this thesis.

2.1 Introduction

Agility has been defined as a rapid whole-body movement with change of velocity or direction in response to a stimulus (196). Change of direction (COD) performance forms the physical foundation for agility, as it incorporates key qualities associated with athletic performance, such as acceleration, deceleration, directional change, and reacceleration (165) with no reaction to a stimulus (31). A range of factors that have been identified by Sheppard and Young (196), that are considered important in determining COD ability can be observed in Figure 2.1. These researchers have identified technique, straight sprinting speed, and leg muscle qualities to be the three key factors in determining COD ability.

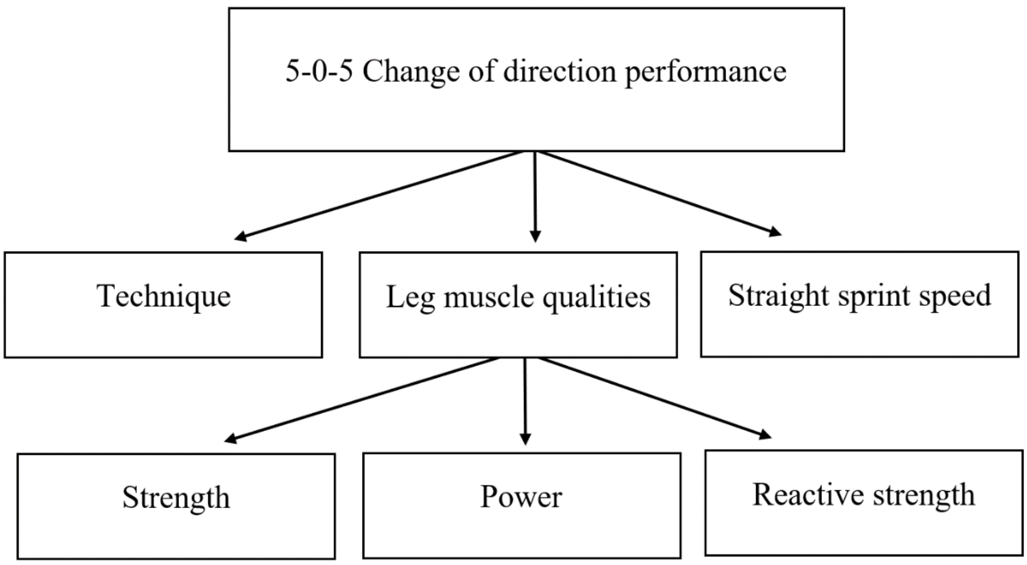

Figure 2.1: Deterministic model of change of direction (re-produced from Sheppard and Young, 2006).

The ability to change direction effectively is considered essential for successful participation in many field and court sport athletes (17, 31) and in recent times, COD performance has been considered one of the determining factors for successful participation in high level sport (77, 82). For example, during elite netball matches, on average, athletes have been shown to perform 63.7 ± 7.6 COD manoeuvres (17), and professional soccer athletes have been reported to perform approximately 700

COD movements throughout a competitive match (26, 122). Furthermore, COD ability is commonly included in athletic testing batteries used for selection in many sports, such as soccer (83), American football (146), rugby league (79), basketball (206), and netball (220). Given the importance of COD, it is logical that this athletic quality needs to be measured and monitored to determine the capability of athletes and the efficacy of subsequent programming.

There are several different types of COD manoeuvres, with one of the most common being the 180° COD, in sports such as soccer (2, 177), basketball (206), and netball (210). The ability to rapidly accelerate, decelerate, turn 180° and reaccelerate again is an important physical quality for most multidirectional sports (53). Several COD tests feature 180° turns, such as the pro-agility (165, 176), Illinois agility test (87), and the 5-0-5 COD test (17). These COD tests are included in the fitness testing batteries of numerous sports (53, 165, 166). Notably, some tests include 'agility' in their title. Coaches should be cognizant that agility encompasses both cognitive and physical performance qualities. Although COD tests have been critiqued for their limited ecological validity (164), they have primarily been used for their discriminative validity (i.e., ability to differentiate athletes of different levels), and therefore can be used for talent identification purposes. Furthermore, 180° CODs may occur as part of pre-planned COD movements in sports such as route running in American football.

The pro-agility test has been commonly used for American football (166, 176, 198) and soccer (231, 232); however, the movements performed within this test do not mimic those commonly seen on the court or field in team sports, that is, performing multiple 180° COD back to back in close confines. In addition to this, some COD tests (e.g., the Illinois agility test) are too long in duration, meaning there is less emphasis on COD ability and more on anaerobic power and linear sprinting ability (165). For example, the Illinois agility test is typically completed in 14–18 seconds (165, 232) and the T-test can have a duration of approximately 10–12 seconds (172, 189) in athletic populations. Therefore, a common test that may be more applicable to on-field/court demands is the 5-0-5 COD test.

Traditionally, the 5-0-5 COD test (Figure 2.2) is performed from a flying start (10 m) and uses one set of timing gates to assess an individual's ability to sprint 5 m, perform a 180° COD, and sprint 5 m back through the timing gates. In recent years, more practitioners have started using a modified 5-0-5 COD test (65, 79, 80, 219). The modified 5-0-5 COD test begins from a stationary start, usually 0.5–1.0 m behind the first timing gate (Figure 2.3). The athlete then sprints through the timing gate to the 5 m/turn line, performs a 180° turn, and sprints 5 m back through the timing gates. This test removes the initial 10-m linear sprint and therefore more closely assesses COD performance for sports such as netball (75, 235), where the court size, rules, and movement patterns, more closely emulate the modified 5-0-5 test. For example, an athlete in the goal shoot position has a relatively small area to work in and therefore does not have the space to sprint 10 m before performing a COD manoeuvre (229). The 180° turn performed in the modified 5-0-5 also well represents the switching between offense and defence in sports such as basketball (209). However, field sports with larger playing fields, such as American football and soccer, may have sport-specific demands which are better suited to the traditional 5-0-5 test. As well as different sports having different COD requirements, positions within sports could use different versions of the 5-0-5 COD test. It is important to note that the modified 5-0-5 COD test will have a lower entry velocity compared to the traditional 5-0-5 assessment, and therefore it may be less challenging in terms of deceleration requirements (53, 56).

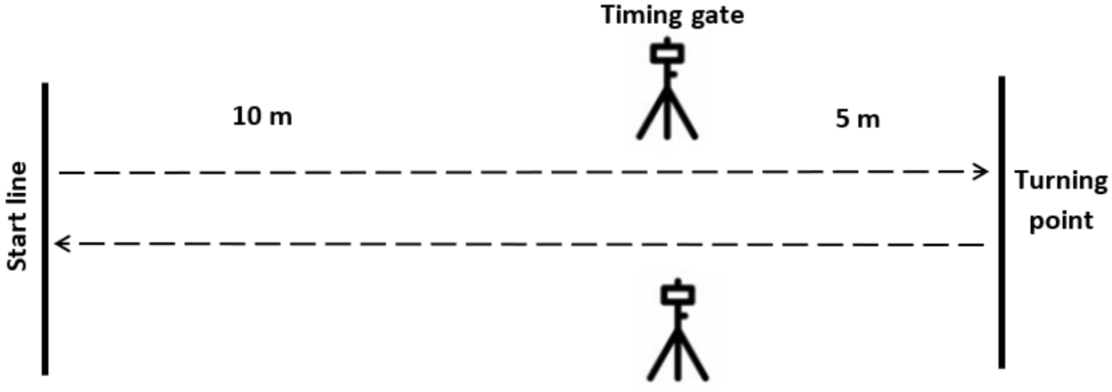

Figure 2.2*:* Set up of the traditional 5-0-5 change of direction test.

The traditional and modified 5-0-5 tests provide the focus of this article. As with all testing, it is important to understand the variability associated with testing, as this provides the practitioner insight into the “real” change associated with COD performance testing. Furthermore, coaches need to have sport, sex, and level specific normative data, so performance comparisons can be made, which in turn can drive programming to better effect. This review focuses on providing coaches and practitioners with such information for the traditional and the modified 5-0-5 COD test and evaluating the reliability of the testing procedures used to date.

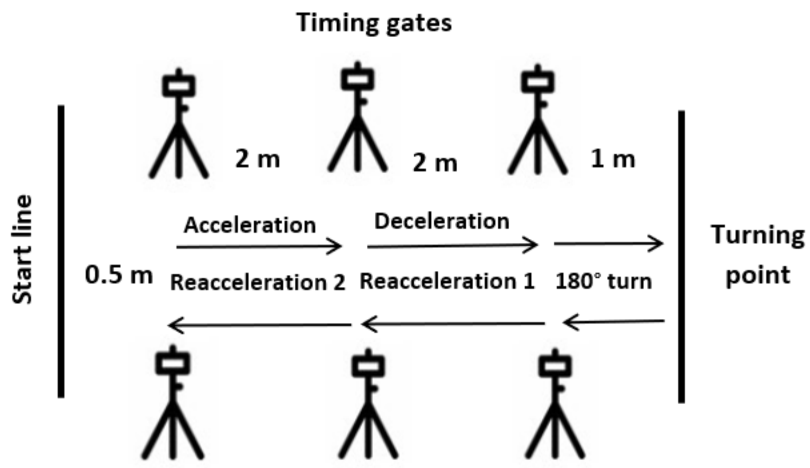

Figure 2.3: Set up of the modified 5-0-5 change of direction test

2.2 Methods

The systematic review was performed according to PRISMA recommendations (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) (155) and the search was performed up to February 2021. Three databases (SPORTDiscus, ScienceDirect, and Google Scholar) were searched using the terms “5-0-5 test,” “5-0-5 agility test,” “modified 5-0-5 test,” and “5-0-5 change of direction”. Reference lists of related papers were also checked for other relevant articles.

Once all of the databases had been searched, duplicates were removed. If by reading the title or the abstract, the authors could clearly identify that the article was not related to COD performance, the article was discarded. When reading the text, the authors identified if the article was a scientific article that came from a peer-reviewed journal. The authors then determined whether the study was related to 5-0-5 COD performance for competitive and social athletes. Once the articles had been analysed, information regarding the sample size, sex, age, sport, level, technology, and 5-0-5 performance was extracted from each paper. Fifty studies were included in this analysis. The authors chose to include articles that, (a) did not differentiate between male and female performance, and (b) did not report performance times, to highlight some of the key gaps within the literature that are discussed throughout the review. The selection process is outlined in Figure 2.4.

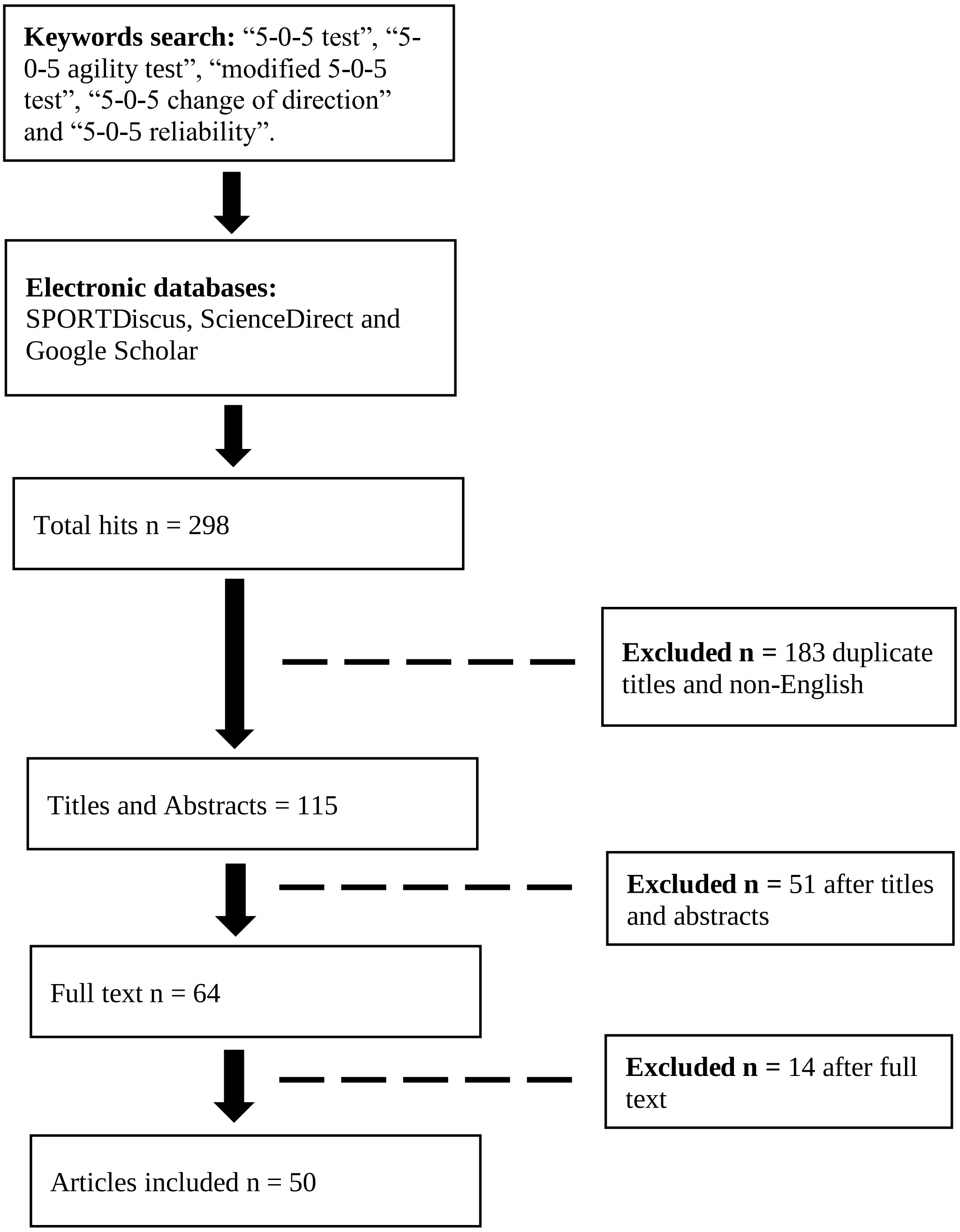

Figure 2.4: Flow diagram of the search strategy and article selection process.

2.3 Traditional 5-0-5 Change of Direction Normative Data

In the ensuing sections, the current body of literature which has used the traditional and modified 5-0-5 COD test will be reviewed and normative results will be discussed in relation to sex, competition level, age, sport, technology, and reliability. For each data set, the weighted average has been calculated (5-0-5 mean time * N/Total N) and presented in Table 2.1 for the traditional 5-0-5 test and Table 2.3 for the modified 5-0-5 test. The percent difference between males and females was calculated using average data ([1-male average/female average]*100). The comprehensive list of studies for the traditional and modified 5-0-5 test has been provided as supplementary information in Tables 2.5 and 2.6 (Appendix C), respectively. It should be noted that the 5-0-5 COD test is often used to detect asymmetries between left and right legs, however, only some studies have reported both left and right leg performance times (119, 140, 142, 204, 219, 222, 223). Asymmetries in COD performance when pushing off the dominant versus non-dominant limb are important for coaches to test, as such asymmetries could be a consequence of an asymmetry in physical qualities (138). Furthermore, these differences in physical qualities may be advantageous in some aspects depending on player sport and position. In other cases, this may be disadvantageous if an athlete needs to be able to perform well off both legs and avoid turning their back on opponents.

The creators of the 5-0-5 test have suggested that it isolates the ability to change direction and is a valid measure of COD performance (60). However, the traditional 5-0-5 test includes a considerable amount of linear sprinting and therefore may not be a true representation of COD ability. The reviewed studies on traditional 5-0-5 test performance include a total of 527 subjects across 31 studies. Five studies ($n = 48$) were not included in the sub-analysis because they were correlational and did not report average 5-0-5 performance data. Jones et al. (110) ($n = 38$) did not differentiate performance times between males and females and therefore could not be included in the between-sex comparison. The weighted averaged summary analysis in Table 2.1 provides an overview of these studies. Two of the studies (204, 223) were removed from this sub-analysis because their data were substantially slower

(~2-3 seconds) compared with other studies and therefore were classed as outliers (*n = 55*). Regarding the sub-analysis, the following observations can be made.

Table 2.1: Weighted averaged traditional 5-0-5 COD performance times across all categories

Category	Sex	N	Average 5-0-5 COD Performance Time (s)	Difference in male/female mean (%)
Sex				
	Combined	400	2.50 ± 0.18	6.03
	Male	300	2.49 ± 0.18	
	Female	62	2.65 ± 0.15	
Level				
Elite	Combined	51	N/A	
	Male	51	2.37 ± 0.32	
	Female	0	N/A	
Sub-Elite	Combined	134	2.58 ± 0.17	2.28
	Male	90	2.57 ± 0.18	
	Female	44	2.63 ± 0.15	
Novice	Combined	215	2.47 ± 0.15	9.20
	Male	159	2.47 ± 0.16	
	Female	18	2.72 ± 0.18	
Age (years)				
Under 16	Combined	64	N/A	
	Male	64	2.66 ± 0.21	
	Female	0	N/A	
16-19	Combined	102	2.49 ± 0.23	9.12
	Male	58	2.39 ± 0.29	
	Female	44	2.63 ± 0.15	
Over 20	Combined	234	2.46 ± 0.15	9.56
	Male	178	2.46 ± 0.12	
	Female	18	2.72 ± 0.18	
Sport				
Soccer	Combined	118	N/A	
	Male	118	2.53 ± 0.26	
	Female	0	N/A	
Basketball	Combined	34	N/A	
	Male	34	2.62 ± 0.21	
	Female	0	N/A	
Rugby Union	Combined	22	N/A	

	Male	22	2.51 ± 0.19
	Female	0	N/A
Rugby League	Combined	57	N/A
	Male	57	2.43 ± 0.16
	Female	0	N/A
Tennis	Combined	0	N/A
	Male	6	2.49 ± 0.13
	Female	0	N/A
Netball	Combined	45	N/A
	Male	0	N/A
	Female	45	2.69 ± 0.14
Cricket	Combined	37	N/A
	Male	37	2.32 ± 0.08
	Female	0	N/A
Lacrosse	Combined	17	N/A
	Male	0	N/A
	Female	17	2.55 ± 0.20
Recreational	Combined	64	2.38 ± 0.12
	Male	26	2.43 ± 0.12
	Female	0	N/A

COD = change of direction; N.B. Several studies did not differentiate between males and females.

2.3.1 Sex

A total of 400 subjects make up this data set for males (*n = 300*) and females (*n = 62*). Note that one study (111) (*n = 38*) did not differentiate between sex and only reported one total average time (2.34 ± 0.12 seconds) for both males and females. Two of the studies (139, 194) that used both male and female participants did not report an average 5-0-5 COD time for either group. Therefore, these studies could not be used for between sex comparisons.

The fastest weighted averaged data was found in male cricket players (2.32 seconds) and the slowest in novice females (2.72 seconds). It was found that on average, males 5-0-5 COD times were 6.03% faster than that of females. This is to be expected given the greater neuromuscular capabilities commonly associated with males compared with females. Readers should note that there was a total of 300 males, with 51 of those being classified as elite athletes, whereas there were only 62 total female athletes, with none being classified as elite. This would affect the results, and it is unknown how this percentage difference would change if the population was of similar numbers and performance levels.

2.3.2 Competition level

The 5-0-5 test is used world-wide across various levels of sport (79, 192). For the purpose of this review, the research has been split into 3 different tiers: novice, sub-elite, and elite. Many inconsistencies were found between study definitions; therefore, the authors categorized athletes based on the following definitions. Elite athletes were defined as those competing at the international and/or national level, whereas sub-elite athletes were defined as those competing at a state/provincial level. Athletes who played club level or social for their sport were considered novice.

Nine studies used novice athletes as their participants. There was ~0.2 seconds (7.78%) range between elite, sub-elite, and novice males and ~0.1 seconds (3.30%) difference between sub-elite and novice females. No researchers have reported assessing elite females, also the female numbers were 80% lower than males. Interestingly, the males' sub-elite score was slower (3.89%) than the novice, which may be in part because of the disparate sample sizes for each category. It seems that most of the research has been undertaken with sub-elite and novice participants. Only 3 of the studies for the traditional 5-0-5 test involved elite athletes, which were male soccer athletes (38, 222). More data are needed on elite athletes to provide more comprehensive normative data. Sports such as netball and cricket, which are commonly performing 180° COD, have only been investigated using novice (105, 173) and sub-elite athletes (48, 219, 230). This may be because of limited access to high-level athletes for research, due to time availability, perceived injury risk, and logistics. More research is needed on elite athletes to determine the utility and reliability of the 5-0-5 COD test for this population.

2.3.3 Age

For age, the data was divided into 3 categories: under 16 years (U16, $n = 64$), 16–19 years ($n = 102$), and over 20 years (O20, $n = 234$). Only 3 studies contained 5-0-5 COD performance data for athletes

U16, which were all male athletes. This is an area that would benefit from further research (i.e., U16, female) to provide better normative data based on age and sex. The difference between males and females across both age categories (16–19 and O20) was very similar (9.20–9.60%). Whether the difference would be the same in younger athletes is unknown, but we would speculate that the difference in pre-peak height velocity (PHV) males and females would be minimal, as up until puberty there are very few performance differences between genders (36). However, more data are needed to support this assumption. The use of biological age rather than chronological age is recommended as performance changes become more disparate with maturity and it allows coaches who work with young athletes to compare and monitor their athletes based on their maturation.

Two studies that both used elite male soccer athletes reported relatively different results. For example, Chaalali et al. (38) used younger athletes (14.5 ± 0.9 years) and reported a mean 5-0-5 COD time of 2.42 ± 0.15 seconds, whereas Torreblance-Martinez (222) used older elite athletes (18.42 ± 0.69 years) and reported faster 5-0-5 COD times for both right (2.28 ± 0.6 seconds) and left (2.29 ± 0.6 seconds) legs. Although the participants in this study were both considered elite and from the same sport, their age, training age, and maturation are likely the cause of their different 5-0-5 times, which could be expected across all sports. This highlights the need for more information around elite athletes, the role of maturation/training age, and different COD tests, especially in sports that perform a large number of directional changes each game (e.g., basketball, soccer, and netball).

2.3.4 Sport

Interaction between sex and sport is problematic given that no research groups have reported both male and female 5-0-5 COD times in the same sport. Female data is only available for one field sport (lacrosse = 2.55 seconds) (119), whereas COD times for male athletes in other field sports range from 2.32 seconds (cricket) to 2.53 seconds (soccer). It did not surprise the authors that cricket players had the fastest COD times, as a big part of scoring runs is running between wickets which involves 180° COD very similar to the 5-0-5 test. In the other field sports, soccer players having the slowest 5-0-5

COD times also intuitively makes sense as the movement patterns require more linear sprinting and 45-degree cutting COD's, compared with field or court sports such as cricket and tennis. Although pre-planned 180° COD is not necessarily built into sports such as rugby codes, athletes may be required to perform 180° directional changes as part of the natural ebbs and flows of the sport. For example, if the ball is intercepted or a turnover occurs, athletes will have to decelerate as fast as possible, perform a 180° directional change, and reaccelerate quickly to get back to a position to defend. Interestingly, the sport that has used the 5-0-5 COD test most in their research is soccer, with 7 of the 31 studies conducted in soccer (5, 22, 38, 113, 140, 160, 222).

Field sport athletes tend to have faster traditional 5-0-5 COD times compared with court sport athletes. This is likely a result of match demands and field size, as field sports have greater space and longer running time before changing direction, compared with court sports such as netball, where athletes are confined to specific areas based on position. Basketball is a court sport that frequently uses the 5-0-5 COD test, with 5 of the studies having basketball athletes as their participants (10, 48, 138, 194, 204). Two of the studies (139, 194) in basketball did not report average 5-0-5 COD performance data but rather reported correlations. In court sports, male tennis players on average are 0.13 seconds quicker than male basketball players, whereas the netball females were 5.6% slower than the male court sport athletes in general. There is very little research on female athletes. For example, netball is a sport that requires frequent 180° COD during games (210), so further research is needed to provide insight into the level these female athletes need to be performing at, and providing more normative data for coaches and researchers.

2.3.5 Technology and reliability

It is important to determine the reliability of a performance test to ensure the results being produced are true indications of performance. This reliability is usually quantified via measurements of absolute consistency (coefficient of variation [CV]) and relative consistency (intraclass correlation coefficient [ICC]) (11). Coefficient of variations provide a simple method for calculating typical error of measurement and are usually considered reliable when equal to or under 10% (103), however when conducting fitness testing, CVs should be as low as possible (224), whereas ICCs above 0.75 are commonly considered to have good to excellent reliability (117). Several studies have investigated the reliability of the traditional 5-0-5 test in various sports and skill levels (presented in Table 2.2). Two of the studies (219, 222) only reported within session reliability, whereas the other 6 studies reported between-session reliability (17, 79, 167, 190, 191, 215). It is more valuable to know the between-session reliability as it provides information on how likely it is to produce the same results if you were to repeat the test on a different occasion, that is, mapping, monitoring, and managing performance changes.

Timing gates are usually used to measure 5-0-5 performance (22 out of 27 studies) with results typically presented as total time (s). Three of the reliability studies (17, 190, 219) used single beam timing gates, whereas another 3 of the studies used dual beam timing gates (79, 167, 215). According to researchers, dual beam timing gates should be used when available as they provide a more accurate and reliable measurement (92). Only three of the studies reported both CV and ICC (167, 219, 222), and of these three studies, only one of those studies reported between session reliability (167). Nimphius et al. (167) reported an ICC of 0.93 and CV of 1.9%, whereas 4 other studies reported ICCs above 0.90, indicating excellent between-session reliability using the timing gates (17, 79, 167, 215). Five of the studies reported CVs between 1.9 and 5.4% (167, 190, 191, 219, 222), the largest variability observed was with novice and sub-elite players (190).

One group of researchers analysed the 5-0-5 test using an infrared Vicon motion capture system (Oxford Metrics, Oxford, United Kingdom) at a sampling rate of 240 Hz (188) to gain three dimensional kinematic data, whereas other researchers used a newly developed "COD timer app" to measure soccer athletes' performance (222). The COD timer app has been shown to have a near perfect correlation with timing gates for the measurement of total time ($r = 0.964$) (14). Similar reliability was observed between the timing gates and the app for the measurement of 6 different trials of each participant (COD Timer app: ICC = 0.67–0.84, CV = 2.2–3.2%). The COD timer app produced the lowest ICC values (Left:

0.70, Right: 0.64), with the test performed on the right leg considered ‘fairly’ reliable and the left leg considered to have ‘good’ reliability. This is a relatively new technology with minimal research surrounding its validity and reliability. More research is needed to determine whether this app is a reliable tool to measure 5-0-5 COD performance in a range of different athlete populations and sports. This new phone technology could be a promising area for future research because it is easily accessible and affordable for many coaches and athletes to use. To the authors’ knowledge, there are no reliability studies that have used elite level athletes for between-session reliability for the traditional 5-0-5 COD test. Based on the results from these studies, coaches can be confident that using the traditional 5-0-5 COD test with timing gates is a reliable way to measure COD performance produced as total time in novice and sub-elite athletes.

Table 2.2: Traditional 5-0-5 COD test reliability studies

Author	N =	Sport	Skill level	Timing technology	Number of trials x sessions (between session length)	Reliability type	ICC	CV (%)
Barber et al., 2016 (17)	52	Netball	Novice	Single beam timing gates	3 trials x 4 sessions (1 week apart)	Between session	0.95	NR
Gabbett et al., 2008 (79)	42	Rugby League	Novice and sub-elite	Dual beam timing gates	3 trials x 2 sessions (2 days apart)	Between session	0.90	NR
Nimphius et al., 2010 (167)	10	Softball	Sub-elite	Dual beam timing gates	4 trials (2 each leg) x 3 sessions (10 weeks apart)	Between session	0.93	1.9
Sawczuk et al., 2018 (190)	59	Variety of sports	Novice and sub-elite	Single beam timing gates	3 trials x 2 sessions (1 week apart)	Between session	NR	R: 5.4 (4.4 -7.0) L: 4.1 (3.4 -5.4)
Sayers, 2014 (191)	15	Variety of sports	Novice	Timing gates and 3D cameras	6 trials x 2 sessions (5-7 days apart)	Between session	NR	2.8
Teo et al., 2016 (215)	26	Recreational	N/A	Dual beam timing gates	3 trials 2 sessions	Between Session	0.96	NR
Thomas et al., 2016 (219)	18	Cricket	Sub-elite	Single beam timing gates	3 trials 1 session	Within session	L: 0.82 R: 0.75	L: 2.5 R: 3.0
Torreblanca-Martinez et al., 2020 (222)	19	Soccer	Elite	COD timer app	3 trials 1 session	Within session	L: 0.70 R: 0.63	L: 3.0 R: 2.6

Key: R= Right leg, L= Left leg, NR= Not reported, ICC Criteria, Poor =0.40; Moderate = 0.40–0.70; Good = 0.70–0.90; Excellent = 0.90, CV Criteria, <10%= Acceptable

2.4 Modified 5-0-5 Change of Direction Normative Data

In more recent years, the use of a modified 5-0-5 COD test has become more common. The reviewed studies on the modified 5-0-5 COD test performance include a total of 178 subjects across 9 studies that reported average modified 5-0-5 COD performance data. The weighted averaged summary analysis in Table 2.3 provides an overview of these studies. Only 9 studies have reported modified 5-0-5 COD data, compared with 31 studies that have reported traditional 5-0-5 COD data. Two of the studies did not report their average performance data (96, 216) and therefore were not included in the analysis. There was an approximate 10% difference in total time between the combined weighted average for the modified 5-0-5 COD data, compared with the traditional 5-0-5 data (modified 5-0-5 COD test 10% slower than the traditional 5-0-5 COD test performance times). This is to be expected, as the modified 5-0-5 COD test has a lower entry velocity as athletes begin from a static start 0.5-1.0 m back from the first gate, whereas athletes have 10 m, to accelerate before passing through the first gate in the traditional 5-0-5 COD test. Regarding the sub-analysis of the modified 5-0-5 COD test, the following observations can be made.

2.4.1 Sex

A total of 178 subjects make up this data set, 136 of which were males. Female only data was entirely absent in the literature. One study did not differentiate between sex (161), whereas another did not report sex (80). The fastest weighted averaged data were found in male cricket players (2.70 seconds), which was also the case for the traditional 5-0-5 test. Because no researchers have reported times for female athletes, no comparisons can be made, and it is unknown what times female athletes would produce in this modified 5-0-5 COD test. We can presume that the difference would be similar to that seen for the traditional 5-0-5 COD test (~6.00%); however, this is speculative and requires further research.

Table 2.3: Weighted averaged modified 5-0-5 COD performance time across all categories

Category	Sex	N	Average 5-0-5 COD Performance Time
Sex			
	Combined	178	2.78 ± 0.11
	Male	136	2.78 ± 0.11
	Female	0	N/A
Competition Level			
Elite	Combined	11	N/A
	Male	11	2.75 ± 0.18
	Female	0	N/A
Sub-Elite	Combined	101	2.75 ± 0.12
	Male	59	2.75 ± 0.11
	Female	0	N/A
Novice	Combined	66	N/A
	Male	66	2.80 ± 0.11
	Female	0	N/A
Age (years)			
Under 16	Combined	57	2.82 ± 0.12
	Male	45	2.79 ± 0.11
	Female	0	N/A
16-19	Combined	68	2.78 ± 0.11
	Male	38	2.85 ± 0.10
	Female	0	N/A
Over 20	Combined	53	N/A
	Male	53	2.73 ± 0.12
	Female	0	N/A
Sport			
Rugby League	Combined	42	N/A
	Male	42	2.77 ± 0.11
	Female	0	N/A
Tennis	Combined	118	2.82 ± 0.11
	Male	76	2.86 ± 0.10
	Female	0	N/A
Cricket	Combined	18	N/A
	Male	18	2.70 ± 0.13
	Female	0	N/A

COD = Change of direction

2.4.2 Competition Level

Five studies have used novice athletes as their participants (65, 79, 96, 158, 216) with 5 studies also using sub-elite athletes (65, 77, 80, 161, 219). There was only a 1.79% difference between sub-elite and novice athlete times. Interestingly, only one group of researchers used elite males as their participants (126). The elite group was made up of 11 subjects with an average performance of 2.75 seconds, which was the same for sub-elite athletes and only 1.79% faster compared to novice athletes. However, coaches and sport scientists should interpret these results with caution, as a greater difference in favour of the elite athletes could be expected if the sample size was similar for both groups. Therefore, we can conclude that it is unclear how elite athletes perform in the modified 5-0-5 COD test. To the authors' knowledge, there are currently no studies that have reported data for novice, sub-elite, or elite female athletes. Also, there are no studies that have performed the modified 5-0-5 COD test with elite female athletes.

2.4.3 Age

It seems that most of the research with the modified 5-0-5 COD test has been performed with athletes aged 16–19 years (*n = 68*. Athletes under 16 years (U16) and those over 16 years (O16) have similar subject numbers (*n = 57* and *n = 53*, respectively). U16 and 16–19 years reported combined (male and female) scores, whereas O20 only had male participants. There was a 2.52% difference between 16 and 19 years combined and U16 combined performance times. This would be expected as most athletes in the 16–19-year age group would be post peak height velocity with better developed neuromuscular capabilities. Interestingly, the largest difference (4.21%) was observed between O20 males and 16-19-year-old males, and a difference of only 2.15% was reported between O20 males and U16 males. This may be because of one group of researchers (158) reporting significantly higher (0.29–0.31 seconds) performance times in 16–19-year-olds with a total of 20 subjects, making up a total of 29.4% of the subjects in this category. No individual female data have been reported; therefore, no comparisons of male and female athletes can be made for the different age groups.

2.4.4 Sport

Like the traditional 5-0-5 COD test, we cannot comment on the interaction between sex and sport as no research groups have reported male and female COD times in the same sport for the modified 5-0-5 COD test. Nevertheless, 6 out of the 9 studies that reported performance data have involved tennis athletes (65, 66, 80, 126, 158, 161). This makes sense as the movement patterns of the modified 5-0-5

COD test are very similar to movements performed during a tennis match. The other 3 studies reported performance times for rugby league (79, 216) and cricket players (219). Conceptually, the traditional 5-0-5 COD test may be better suited for cricket players than the modified 5-0-5 COD test as the running lane distance is approximately 20 m, which is similar to the distance of the traditional 5-0-5 COD test (15 m). Regardless, the male cricket players on average were 0.16 seconds faster than the male tennis players, and 0.07 seconds faster than the male rugby league players.

One study used a range of different athletes (handball, tennis, and soccer), however, did not report the performance data as the research was correlational focused (96). There is a clear lack of research using the modified 5-0-5 COD test, with most studies choosing to use the traditional test. However, some court sports, such as tennis and netball, that require short sharp changes of direction because of match demands and confined areas of play, could benefit from using this modified 5-0-5 COD test. There is a lack of research focusing on female athletes for all sports where COD is an important factor. Future research needs to investigate the use of this modified test in sports such as netball and volleyball using both male and female athletes.

2.4.4 Technology and reliability

Timing gates seem to be the only technology that has been used to measure performance for the modified 5-0-5 COD test (17, 79, 214, 216, 219). It would be beneficial for future researchers to focus on determining the reliability of different technologies that could be used to measure COD performance. For example, the COD timer app is reliable when measuring traditional 5-0-5 COD performance; therefore, it is hypothesised that it would also be a reliable measurement tool for the modified 5-0-5 COD test. The use of other technologies such as radar guns and inertial measurement units could also be of interest when assessing COD performance; however, there is minimal research that has used this technology.

Table 2.4: Modified 5-0-5 change of direction test reliability studies

Author	N=	Sport	Skill level	Timing technology	Number of trials and sessions (between session length)	Reliability type	ICC	CV (%)
Barber et al., 2016 (17)	52	Netball	Novice	Single beam timing gate	3 trials 4 sessions (1 week apart)	Between session	0.97	Not reported
Taylor et al., 2019 (214)	110	Soccer	Sub-elite	Single beam timing gates	4 trials (2 each leg) 2 sessions (1 week apart)	Between session	Pre-PHV Left: 0.54 Right: 0.65 At-PHV Left: 0.68 Right: 0.78 Post-PHV Left: 0.26 Right: 0.54	Not reported
Thomas et al., 2015 (216)	14	Soccer and rugby league	Novice	Single beam timing gates	3 trials 1 session	Within session	0.89	1.7
Thomas et al., 2016 (219)	18	Cricket	Sub-elite	Single beam timing gates	3 trials 1 session	Within session	Left: 0.79 Right: 0.83	Left: 2.0 Right: 2.6
Gabbett et al., 2008 (79)	42	Rugby league	Novice and sub-elite	Dual beam timing gates	3 trials 2 sessions (2 days apart)	Between session	0.92	Not reported

Key: R= Right leg, L= Left leg, NR= Not reported, ICC Criteria, Poor =0.40; Moderate = 0.40–0.70; Good = 0.70–0.90; Excellent = 0.90, CV Criteria, <10%= Acceptable, PHV= Peak-height velocity

To the authors' knowledge, only 5 studies have determined the reliability of the modified 5-0-5 COD test (Table 2.4). Two of the studies reported within-session reliability (216, 219), whereas 3 of the studies reported between-session reliability (17, 79, 214). Two of the studies, led by Thomas et al. (216, 219), were the only studies to report absolute consistency (CV) with all values < 5%. Barber et al. (17), found the modified 5-0-5 COD test to have high between session relative consistency (ICC = 0.97), which was similar to Gabbett et al. (79), who also determined that the modified 5-0-5 COD test had high between session consistency (ICC = 0.92). Conversely, the most recent reliability study in soccer athletes (214) that used pre-peak, mid-peak, and post-peak height velocity subjects, reported low to-moderate consistency of the modified 5-0-5 COD test (ICC = 0.26 to 0.78). No reliability testing has been performed using elite athletes, therefore the variability of this test for higher-level athletes is unclear. Based on the results of the existing studies, coaches and practitioners can reliably test novice and sub-elite athletes using the modified 5-0-5 COD test.

2.5 Conclusion

Traditional COD ability of male athletes is better understood given there were 300 male athletes, compared with 62 female athletes. It was found that males were on average 6.03% faster than females. Elite males were 7.78% faster than sub-elite and novice males and sub-elite female athletes on average were 3.30% faster than novice female athletes; however, no data were found for elite female athletes. As well as a lack of female data within the research, only 3 out of 31 studies had U16 participants for the traditional 5-0-5 COD test. Continuing the male-centric data emphasis, results for only male athletes were found for the modified 5-0-5 COD test, the fastest athletes being male cricket players (2.70 seconds).

After completing a sub analysis for all studies that have reported traditional and modified 5-0-5 COD performance data, several gaps and limitations have been identified. First, there is a lack of female representation, especially within the modified 5-0-5 COD performance data. Second, there is a lack of research investigating COD capability in youth athletes, with a majority of the research having participants over the age of 20 years. Third, most of the research for both the modified and traditional 5-0-5 COD test has been completed in tennis, soccer, and basketball, whereas sports such as netball, volleyball, and cricket, which often require athletes to perform rapid COD, seem to be under-represented in the research. Fourth, both versions of the 5-0-5 COD test are reliable; however, all studies were performed with novice or sub-elite athletes; therefore, the variability associated with elite athletes is unknown. Fifth, most reliability studies have been performed with timing gates, which seem to be a reliable measurement device; however, more information on other devices such as the COD timer app is needed. These devices only provide a total time for COD performance and encompass multiple athletic qualities, such as acceleration, deceleration, 180° turn ability, and reacceleration. The use of a sub-phase approach to measuring 5-0-5 COD performance could benefit coaches and practitioners by providing greater diagnostic information for COD. Finally, CVs and ICCs were reported in only 4 studies, and only one research group has provided a comprehensive statistical analysis of between-session/test-retest of 5-0-5 COD test reliability.

2.6 Practical Applications

Several coaching practical applications have come from this review. The normative data (Tables 2.1 and 2.3) provided in this review will be valuable information for coaches because it allows them to compare their athletes to other athletes of the same sport, sex, and level of performance. There is a sufficient amount of normative data for male novice and sub-elite athletes; however, it is evident that further research is needed to develop female and elite-level norms. Coaches can be confident that using timing gates to measure traditional and modified 5-0-5 COD performance is a proven reliable method for novice and sub-elite athletes. Dual beam timing gates should be used, when possible, to provide a more accurate measure. Although COD tests provide a good indicator of physical ability, they do not consider the reactive components that have a high ecological validity with many aspects of team sports. However, the 5-0-5 COD test appears to offer a reliable means of monitoring COD progress, which is useful for evaluating conditioning programs or may be useful for return to play decision-making following injury. Finally, the 5-0-5 COD test has good discriminant validity. It can be used to differentiate between athletes of different levels, which may assist coaches through talent identification and athlete monitoring.

Scientific practical applications are also important to highlight. Currently, only timing gates and the COD timer app have been used to produce a total time for such COD tests, which is of limited diagnostic value. The 5-0-5 COD tests require a range of different motor qualities such as acceleration, deceleration, turning ability, and re-acceleration. By measuring these separate sub-phases and the associated leg strength qualities, it is proposed that scientists and coaches can be more targeted with feedback and programming to improve COD and sporting performance. Before such an approach, the following processes need to take place: (a) establish whether each of the COD phases can be measured reliably; (b) establish the strength/power qualities that are important determinants of each phase; (c) investigate whether these qualities can be measured reliably and thereafter their predictive ability; and, (d) discuss and examine the exercise and programming considerations to improve these qualities.

CHAPTER 3 - NEW PERSPECTIVES OF THE TRADITIONAL AND MODIFIED 5-0-5 CHANGE OF DIRECTION TEST

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

Reference:

Ryan, C., Uthoff, A., McKenzie, C., & Cronin, J. (2023). New perspectives of the traditional and modified 5-0-5 change of direction test. Strength and Conditioning Journal, 45(1), 83-92.

3.0 Prelude

In the previous two chapters, it was emphasised that COD ability was essential for successful participation in many field and court sports. In Chapter 2, it was identified that there was a paucity of research on female athletes, netball athletes and elite athletes. Additionally, it was identified that timing gates were the most common and reliable piece of technology for measuring 5-0-5 COD performance, however only a total time was given. It still remained unclear the key neuromuscular components underlying COD ability, given the simplicity of the current COD deterministic model used by Sheppard and Young (196). Given this information, a need for a new COD deterministic model is needed to provide coaches and practitioners with a deeper understanding of COD performance. Additionally, given the limitations of providing only total time as an indication of 5-0-5 COD performance, the need for an advanced diagnostic protocol seems of importance, in order to provide coaches with more granular insight into COD needs. Therefore, the aim of this chapter was to propose a new COD model, in the context of the 5-0-5 test and propose a new assessment for measuring 5-0-5 COD ability. This may allow coaches and practitioners to become more targeted with their feedback and programming to improve COD performance.

3.1 Introduction

The ability to change direction effectively is considered essential for successful participation in many field and court sport athletes and can be considered one of the determining factors for elite level athletes (17, 77). Change of direction (COD) incorporates key qualities associated with athletic performance such as acceleration, deceleration, and directional changes (165). Sheppard and Young (196) have identified a range of factors that are deemed important in determining COD ability (see Figure 3.1). It has been identified that technique, straight sprinting speed, and leg muscle qualities are the three key factors underpinning COD ability. Furthermore, the key determinants of the leg muscle qualities are identified as strength, power and reactive strength (196). We contend, that though the model provides a fundamental understanding of the components of COD, better diagnostic models could be developed in tandem with specific COD tasks/testing.

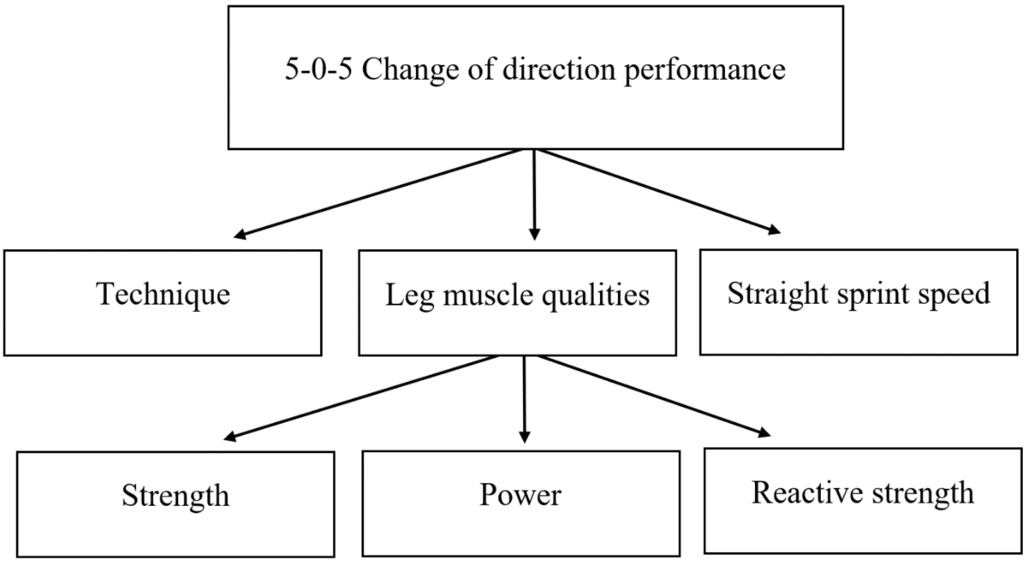

Figure 3.1: Deterministic model of change of direction (re-produced from Sheppard and Young, 2006).

There are several different COD manoeuvres, with 180° COD being one of the most common for many court and field sport athletes. Numerous multidirectional sports require an athlete to rapidly accelerate, decelerate, perform a 180° turn and then reaccelerate again (53). The traditional 5-0-5 COD test is one of the many COD tests that features a 180° turn. This test requires an athlete to sprint 15 m before performing a 180° COD, therefore a large percentage of the time is spent performing linear sprinting. However, the modified 5-0-5 COD test (see Figure 3.2) seems to have become more common in recent years. This version of the 5-0-5 COD test requires less sprinting (i.e., a total of 10 m), therefore a greater percentage of the time is spent performing the COD manoeuvre compared to the traditional version. The modified 5-0-5 COD test would seem more suitable for court sport athletes such as netball, tennis, and basketball, as players have limited space to perform COD movements.

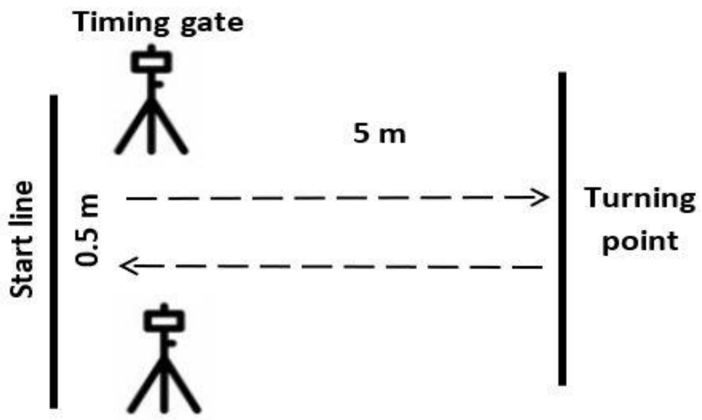

Figure 3.2: Set up of the modified 5-0-5 change of direction test

COD performance is measured as a total time and the practitioner can also compare left and right COD ability/asymmetry. Given that COD is a complex task that involves several athletic qualities such as, acceleration, deceleration, 180° turn and reacceleration, we contend that a total time gives very little insight into the component parts of COD. Each of these athletic qualities is underpinned by differential neuromuscular capabilities (112). Therefore, it is important that tests are able to assess and distinguish between the different COD phases, in order to improve our understanding of COD and effectively program to enhance specific neuromuscular capabilities which will translate to improved COD ability and game performance. We propose a model as shown in Figure 3.3 as an alternative approach to analyse performance, which in the context of this article is 5-0-5 COD ability. Prior to exploring this model in more detail in the second part of this article, a critique of traditional and modified 5-0-5 COD testing is undertaken.

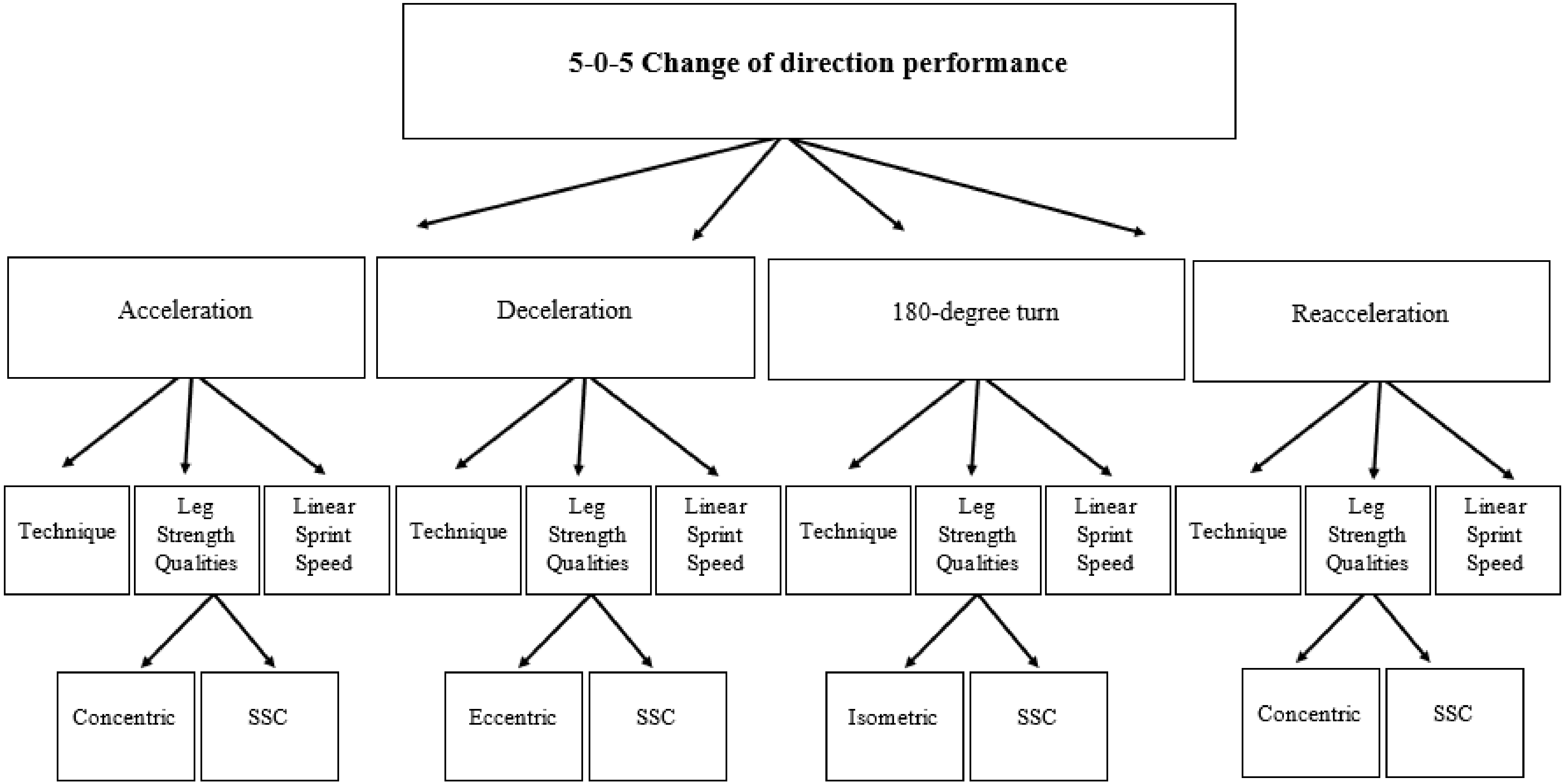

Figure 3.3: Proposed COD deterministic model

Key: SSC – stretch-shorten cycle

3.2 Old Perspectives of the 5-0-5 Change of Direction Test

In the current literature, the discussion of the 5-0-5 COD test is based on data that has only measured total time to complete the test. By providing a total time for a COD test, you are assuming that COD is one athletic quality, when in fact it is a combination of different qualities. From the literature reviewed, researchers have only investigated the relationship between different strength qualities and total 5-0-5 COD time (4, 110, 112, 144, 206, 207, 216, 219, 239). Researchers have attempted to investigate the relationship between leg strength qualities such as concentric, eccentric and isometric strength with this overarching measure (total time), without attempting to break down the COD test further into sub-phases. Though we can make educated hypotheses as to which leg strength qualities are important for different phases of the 5-0-5 COD test, definitive research is lacking as to the importance of various leg strength qualities that are important during the sub-phases of the 5-0-5 COD test. This section of the review will focus on the existing research and old perspectives of the 5-0-5 COD test in relation to leg strength qualities.

3.2.1 Concentric strength

Dynamic actions such as COD, occur when a muscle actively develops tension, such actions may either be isometric, concentric or eccentric. Concentric muscle actions occur when muscular tension rises and the muscle shortens and is often measured through, concentric only muscle actions such as box squats and squat jumps, or via an isokinetic dynamometer (15). It has been suggested that an athlete requires sufficient concentric strength during the acceleration and reacceleration phase of the 5-0-5 COD test (207), however no research currently exists with this 5-0-5 test isolating each of these phases. Therefore, no correlational research currently exists between the phases of COD performance and different strength qualities.

The relationship between concentric strength and total 5-0-5 COD time however, has been explored by numerous research teams (4, 206, 207, 239). Young and colleagues (239) reported non-significant correlations ($r = -0.1$ to 0.54) between various COD manoeuvres (20-60° unilateral and bilateral COD tests) and concentric power measured via an isokinetic dynamometer. This may be due to several reasons. Firstly, comparing total time is not an ideal method, as only a small amount of time is spent accelerating, and therefore requiring concentric muscular capabilities. Secondly, the concentric assessment chosen is not specific to the COD test movement. For example, Young and colleagues (239) assessed concentric strength through isokinetic dynamometry, involving the extension of the knee joint (i.e., open kinetic chain movement), whereas performing a COD movement requires closed kinetic chain movement at the ankle, knee and hip.

Spiteri and colleagues (207) reported a significant (r = 0.791, p = 0.001) correlation between concentric strength and total 5-0-5 COD time for female basketball athletes using a multi-joint, closed kinetic chain movement which required concentric action via triple extension at all three joints (i.e., box-squat). Because the concentric assessment chosen replicates similar muscular and kinematic actions required when changing direction, it may explain the strong correlation found between variables. While the box squat, and other forms of vertically-oriented concentric assessments might be used to determine concentric muscle capabilities related to acceleration, vertically orientated strength may not transfer to horizontally dominant tasks (98). Therefore, practitioners may wish to use a concentric test, such as a standing broad jump in the horizontal direction, where the vertical and horizontal ground reaction forces can be determined.

3.2.2 Eccentric strength

An eccentric muscle action occurs when the distance between the origin and insertion of the muscle is increased (i.e., the muscle is lengthened), while force is developed within the muscle (15). It has been proposed that an athlete requires a sufficient amount of eccentric muscular strength during the deceleration/braking phase to reduce momentum to allow rapid COD movements to occur (37, 118, 207). This is further supported by empirical findings that show significant relationships (r = -0.53 to -0.89) between eccentric muscle strength and COD performance (110, 112, 206, 207).

Jones and colleagues (110, 112) measured eccentric strength via an isokinetic assessment and reported a significant inverse relationship (r = -0.60 to -0.63) between maximal knee flexor eccentric strength and traditional 5-0-5 COD performance time. Greater eccentric knee flexor strength has been found to enable faster athletes to complete the COD within a significantly shorter braking time, therefore resulting in a faster transition out of the COD and into the reacceleration phase of the movement (207). Additionally, researchers have also reported significant inverse relationships (r = -0.53 to -0.67) between maximal knee extensor eccentric strength and traditional 5-0-5 COD time (110, 112). Athletes with greater eccentric knee extensor strength have been found to decelerate more rapidly compared to players with weaker eccentric knee extensor strength during the steps immediately before a 180° COD (110, 112). Therefore, athletes with greater eccentric knee extensor strength can enter at faster approach velocities as they are capable of tolerating the high braking ground reaction forces (GRFs) associated with a faster approach, and therefore achieve significantly faster COD performance times.

Another eccentric assessment that has been used is the box squat (207), which required movement at the ankle, knee and hip joint. This research group reported eccentric strength as the main predictor for total 5-0-5 COD performance (r = -0.89). This research group also concluded that there is a greater emphasis on eccentric strength when the severity and number of directional change increases. As increased force application during the braking/deceleration phase of the movement is required to decelerate an athlete’s momentum (31), the greater number and degree of directional changes increases the contribution from eccentric muscle strength.

It is evident from the available literature that eccentric strength has a large influence on COD performance, however like concentric strength, currently no research has attempted to isolate the phases of the 5-0-5 COD test (i.e., acceleration, deceleration, 180° turn and reacceleration) and explore the relationship between eccentric strength with each phase. Stronger relationships may be observed between lower body eccentric assessments and the deceleration phase of the 5-0-5 COD test (both modified and traditional), as this phase is theorised to primarily be deceleration, which in turn has a large emphasis on both the stretch shorten cycle (SSC) and eccentric muscular capabilities (112).

3.2.3 Isometric strength

During an isometric muscle action, the muscle actively develops tension but no movement occurs (15). The plant phase (amortization phase) of the 180° turn in the 5-0-5 COD test is thought to require great amounts of isometric strength (207). The relationship between isometric strength and total 5-0-5 time has been explored by several research teams (207, 216, 219). Collegiate athletes' bilateral isometric mid-thigh pull (IMTP) peak force (PF) is significantly inversely related to total time for the modified 5-0-5 COD test ($r = -0.57$) (216). That is, athletes that produced high IMTP PF had lower total times in the modified 5-0-5 COD test, therefore resulting in better performance. Very strong, significant inverse relationship was also reported between bilateral IMTP relative PF (PF/body mass) and 5-0-5 COD in female basketball athletes (207).

Unilateral IMTP has also been used to measure isometric leg strength with moderate-to-large significant inverse correlations being reported between both left and right leg IMTP PF and traditional 5-0-5 COD total time on both legs (505 L: $r = -0.65$; 505 R: $r = -0.47$) (219). Interestingly, these researchers reported no significant correlation (r = -0.31 to -0.44) with any single leg IMTP condition with total modified 5-0-5 COD time. It is evident from the research that some aspects of the 5-0-5 COD test require isometric strength, however currently only total time is being measured for the 5-0-5 COD test, whereas it has been proposed that only the plant phase of the 180° turn requires sufficient isometric strength (112, 207).

3.2.4 Reactive strength (stretch shorten cycle)

Reactive strength can be defined as the ability to quickly change from an eccentric to a concentric contraction (144). The relationship between COD and reactive strength has been investigated using the drop jump (DJ) and countermovement jump (CMJ) tests. Jones and colleagues (110) reported low, non-significant correlation between DJ height and traditional 5-0-5 COD time (r = -0.29) and a moderate significant correlation between CMJ height and traditional 5-0-5 COD time (r = 0.50). This suggests that slow SSC (ground contact times >0.25s) capability is of greater relevance during the 5-0-5 COD test compared to fast SSC (contraction time <0.25s) capability (71, 72) given greater flexion at the knee, hip and ankle during a 180° turn i.e., greater movement specificity

The 180° turn appears to be a unilateral reactive movement, which therefore would be expected to require a high level of lateral reactive strength. Given the multidirectional nature of COD tasks, investigators have explored the relationship between vertical, horizontal and lateral jumping performance and COD performance using a 45° sidestep test (95). Weak correlations were reported between lateral jump performance and COD performance (r = -0.12), however weak correlations were also observed for horizontal and vertical jumps (r = -0.15 and -0.28 respectively). It would be expected that this r-value would be small, as the majority of the COD test is spent in linear motion, which does not require large amounts of lateral force. Furthermore, it could be expected that the 180° turn would require greater amounts of lateral strength compared to the 45° cut movement due to the nature of the 180° turn. It was observed that during a 180° turn and sprint task that triple extension of the plant/take off leg is occurring, as well as abduction at the hip (99), compared to the 45° cut movement, where that foot and body is already facing in the intended direction of travel. Stronger correlations were reported by Falch and colleagues (63) between horizontal and vertical countermovement jumps and 5-0-5 COD performance (r = -0.26 to -0.57), however no measurements were taken for lateral reactive strength. Although there is a paucity of research in this space, the authors believe it is a promising area for investigation and will provide coaches with greater insight into the neuromuscular capabilities required for better COD performance.

3.2.5 Summary of Old Perspectives

Based on the current research, it is evident that concentric, eccentric, isometric and reactive strength all play a role in 5-0-5 COD performance, however currently only total time of the 5-0-5 COD test is provided. This provides limited diagnostic value, and we feel that practitioners and coaches would be better equipped to provide valuable programming information to their athletes if the 5-0-5 was divided into sub-phases.

3.3 New Perspective on the Modified 5-0-5 Change of Direction Test

One way of adding diagnostic value to the modified 5-0-5 is by adding two extra timing gates into the modified 5-0-5 test to provide five different split times (see Figure 3.4), which theoretically will measure different aspects of COD (i.e., acceleration, deceleration, 180° turn and reacceleration). By dividing the test into sub-phases, it can offer more refined and targeted diagnostics around COD ability. This section of the review will discuss each sub-phase of the modified 5-0-5 COD test (acceleration, deceleration, 180° turn and reacceleration) and the leg muscle qualities associated with each phase.

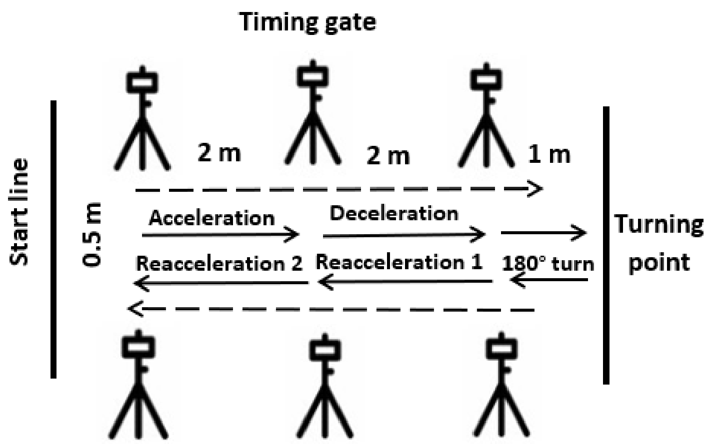

Figure 3.4: Modified 5-0-5 COD test with additional timing gates

By taking a new approach to the modified 5-0-5 COD test, better diagnostics in specific phases of COD performance is possible. For example, athletes that have great acceleration, but poor decelerative ability, can be identified, which gives insight into the specific training needed. The modified 5-0-5 COD test can be split into five different phases: 1) acceleration; 2) deceleration; 3) 180° turn; 4) reacceleration

1; and 5) reacceleration 2. Traditionally, only one timing gate set at the start and finish line has been used to quantify total time. However, the use of multiple timing gates could be used to break up the 5-0-5 COD test into different phases, thereby broadly assessing, acceleration, deceleration, COD, and reacceleration. This provides coaches and sports scientists with a deeper understanding of their athlete's performance ability and identifies areas of strengths and weaknesses that may help improve their overall COD performance. A brief definition and description of each split and sub-phase are detailed in Table 3.1, if two extra timing gates were added, as shown in Figure 3.4. It is acknowledged that it is difficult to determine exactly when acceleration and deceleration are occurring, however, the phases of the 5-0-5 COD test have been defined in an attempt to clarify how each of the sub-phases, based on the time intervals, could be measured using timing gates. To be more exact in the sub-phase analysis, advanced technology such as inertial sensor or radar technology could be implemented. That is, technologies such as radar (30 Hz) and inertial sensors such as Plantiga (416 Hz) provide a lot more information about what is happening in between the time intervals and therefore a greater appreciation of acceleration, deceleration, COD and reacceleration.

Although all these phases would require a well-developed SSC ability, some phases may also emphasize other neuromuscular capabilities such as concentric, eccentric and isometric strength. As well as having certain neuromuscular capabilities, athlete's technique needs to be optimised in relation to the kinematic needs of each phase. This section will focus on the four proposed phases of the 5-0-5 COD test and explore the neuromuscular and technical qualities that underpin each.

Table 3.1: Split, sub-phase, definition, and strength quality for the 5-0-5 COD test

Split	Name of sub-phase	Definition	Quality
1	Acceleration	Rate of change in velocity. From start line to first timing gate (2 m).	Concentric strength and SSC
2	Deceleration	Slowing of the body. From second timing gate to third timing gate (2 m).	Eccentric strength and SSC
3	180° turn	One step before and after the 180° turn. From third timing gate to turn line and back through the third gate (2 m).	Lateral reactive strength (SSC) and isometric strength
4-5	Reacceleration	Rate of change in velocity with a reactive start. From third timing gate to finish (4 m)	Concentric strength and SSC
1-5	Total time	5-0-5 COD test total time. From the first timing gate (0 m) to the first timing gate (10 m).	All qualities

3.3.1 Acceleration phase

Acceleration is defined as the rate of change of velocity or how quickly an athlete can increase their velocity (123). In the context of the modified 5-0-5 COD test, we have defined the acceleration phase from the start line to the 2 m timing gate. Whether the entirety of this split would be acceleration we are unsure, more advanced technology would be needed to determine this.

In the modified 5-0-5 COD test, athletes must accelerate from a stationary standing start, approximately 0.5 m back from the first timing gate (80). In many court sports such as netball and volleyball, athletes are often limited to linear accelerations < 2.5 - 5 m before changing direction (197, 239), as they are typically confined to a relatively small area (100). Therefore, the modified 5-0-5 COD test is more specific to these types of sports.

Some researchers have reported that relatively shorter sprints (<10 m), which is primarily acceleration, require large contributions of concentric muscle contraction (91). There is a plethora of evidence concluding that propulsive forces associated with acceleration require an emphasis on concentric strength (25, 137, 202, 207). These findings highlight the importance of maximal concentric force production during the initial acceleration phases. Therefore, increasing muscular peak force during horizontal concentric muscle actions may result in improved acceleration performance (94, 233). It therefore intuitively makes sense that the acceleration phase of both the traditional and modified 5-0-5 COD test would require a great deal of horizontal concentric strength, as well a well-developed SSC ability. To the authors knowledge, no research has successfully isolated this sub-phase (acceleration) in the 5-0-5 COD test.

3.3.2 Deceleration phase

Deceleration has been defined as the reduction in velocity of an athlete (211). In the context of the modified 5-0-5 COD test, the deceleration phase has been defined as the distance from the second timing gate placed at 2 m to the third timing gate placed at 4 m. Similar to the acceleration phase, it is unknown whether this would be the exact duration of deceleration as it is likely occurring at different times given the technique and neuromuscular capability of different athletes.

There is an abundance of literature which has investigated the kinematics and kinetics of acceleration whilst running (97, 125, 162); however for many sports that require COD, slowing the body's momentum (deceleration) is vital to the success of the movement (97). To effectively perform a 180° COD movement, athletes need to be able to handle the high magnitudes of braking forces over a short period of time during the deceleration phase (97). Several research groups have investigated the relationship between eccentric strength and deceleration (time to stop) ($r = -0.60$ to -0.68), with many groups suggesting that eccentric strength is important for the deceleration phase of a 180° COD task (84, 90, 97, 112), however to the authors knowledge, there is no current research that has attempted to isolate this deceleration phase and determine neuromuscular best predictors of this phase. During the deceleration phase, greater relative braking impulse and mean forces are fundamental to reduce the velocity of the centre of mass (54). Therefore, an athlete needs to have substantial eccentric horizontal strength to effectively perform the deceleration component of a 180° COD.

Currently, the relationship between eccentric strength and 5-0-5 COD has only been investigated using total time or deceleration independently (i.e., linear sprinting). There is a paucity in the research looking at eccentric strength and deceleration relationship in existing COD tests such as the modified 5-0-5 COD test.

3.3.3 180° Turn

For the modified 5-0-5 COD test, the 180° turn sub-phase has been defined as one step before and one step after the 180° turn, which is timed from the third timing gate to the turn line and back through the third timing gate (total of 2 m). The 180° turn has been reported to require a significant amount of lower body isometric strength (207), however, studies that have directly measured this have only investigated the relationship with total 5-0-5 COD time (205-207, 216).

180° COD is primarily a unilateral movement which has been shown to have contact times between 0.24 and 0.40 seconds during the planting of the foot at the end of the deceleration phase (18, 205, 207). Researchers believe that possessing a sufficient amount of isometric strength would be beneficial during this 180° turn in order to maintain the required body positioning throughout the COD (207). Whether this is the case however, is difficult to determine as shown in Figure 3.5, it appears that there is minimal isometric activity of the legs during the turn, as there is a lot of movement occurring at the knee joint. From the video graphic analysis, it would seem that lateral reactive strength (SSC) would be of most importance during this sub-phase. Certainly, more research is needed to support such a contention and the importance of isometrics in the turn.

Figure 3.5: Elite netball athlete performing the 180° turn

Another key determining factor for COD according to the Sheppard and Young model (196) is technique, which may also have an effect on the contribution from different leg strength qualities. The technical differences of two different athletes performing the same 180° turn can be observed in Figure 3.6. Athlete A has a lower body position and greater flexion occurring at the knee joint. Athlete B has a more upright body position and less flexion occurring at the knee joint and so the leg strength emphasis requirements may differ. As a result, the body position and elastic energy stored in the leg musculature may advantage athlete A in terms of a faster turn and quicker COD performance. It needs to be acknowledged that if the angle, force and power profiles were examined, there would be braking and propulsive requirements during the 180° turn execution step, thus eccentric, concentric, and reactive strength will still be important.

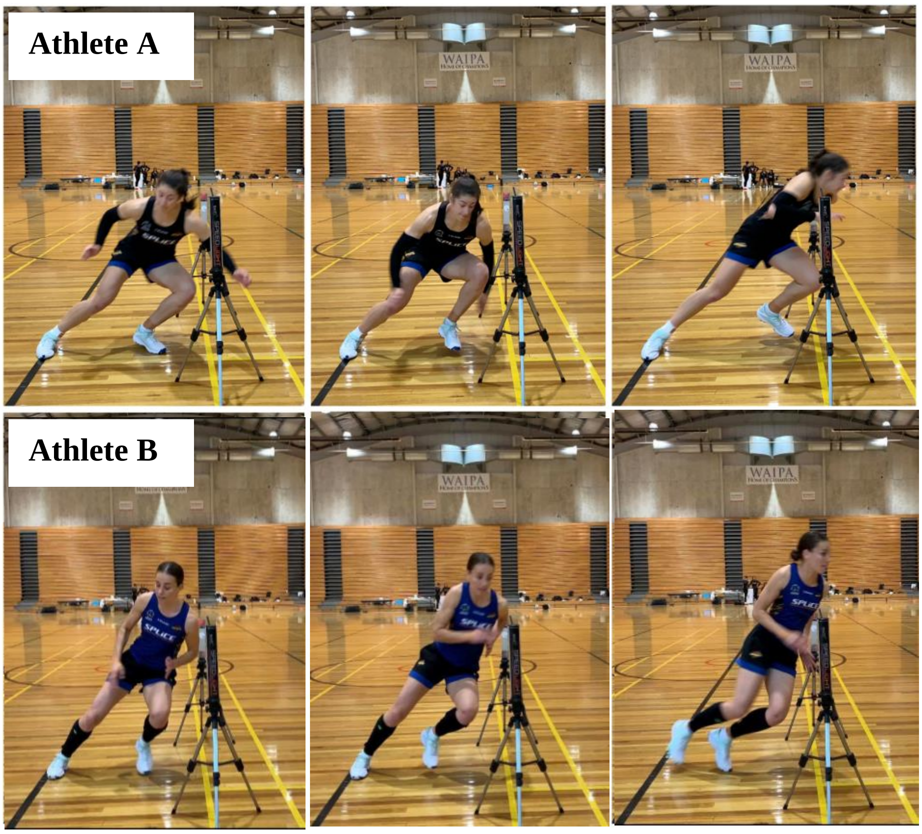

Figure 3.6: Technique comparison between two elite netball players for a 180-degree turn.

Currently no test that has successfully isolated this sub-phase of the 5-0-5 COD test. Therefore, it is difficult to conclude which leg strength qualities are critical determinants of performance. However, it intuitively makes sense that lateral reactive SSC ability plays an important role; though, the magnitude of this importance will depend on different factors such as technique and leg strength. Given the importance of COD in most field and court sports, more research should investigate and isolate this phase, as well as determine the associated key strength capabilities.

Interestingly, researchers have attempted to isolate 180° COD ability with the COD deficit test (166). The COD deficit documents the effect or additional time that one 180° directional change requires when compared to a pure linear sprint over the same distance. This test was first used by Nimphius and Colleagues (166) with Division I American Football players. The athletes performed a 40-yard sprint test through timing gates, with a 10-yard split. Pro-agility COD performance was also assessed using timing gates, allowing for a split time during the first 10 yards of the test, which included a 5-yard sprint into and out of a 180° COD. The "COD deficit" was then calculated as the difference between the 10-yard split time during the 40-yard sprint and the 10-yard split with a 180° COD (165). Although the COD deficit attempts to isolate COD ability, it still includes parts of the deceleration and reacceleration phase. This test also requires multiple trials using different tests. Therefore, it would be more efficient to be able to quantify deceleration and COD within the same COD test.

3.3.4 Reacceleration phase

In some aspect, the reacceleration phase is similar to the acceleration phase, however it can be more accurately defined as the rate of change in velocity with a reactive start. We have defined this phase for the 5-0-5 test from the re-entry into timing light three (i.e., out of the COD) and all the way to timing light one (i.e., start and finish line).

The reacceleration phase occurs after the COD has been performed and differs from the acceleration phase in following ways: 1) the acceleration phase begins 0.5 m back from the first timing gate, whereas the reacceleration begins 1 m back from the third timing gate, which technically could affect the entry velocity of the centre of mass into the third timing gate; 2) the reacceleration phase has a reactive lateral start, compared to the acceleration phase which starts from a stationary position with the body/feet facing in the intended direction of travel; and, 3) athletes will likely reach higher velocities and peak acceleration during this phase as they have a greater distance (4 m) compared to the acceleration phase (2 m) as they don't have to perform a subsequent deceleration.

During deceleration, the application of greater braking force and impulse results in increased storage and utilisation of elastic energy as the muscle lengthens under eccentric load (54, 97, 205). This elastic energy is then available for the subsequent movement (i.e., COD) and theoretically allows for greater propulsive forces during the reacceleration phase, which can result in shorter ground contact times and therefore greater exit velocities (54, 86).

This reacceleration phase is mainly linear and requires similar leg strength qualities to those required during the initial acceleration phase (i.e., SSC and horizontal and vertical concentric strength) (207), as evidenced in Figure 3.6, athlete A producing greater knee flexion, which potentially results in greater stored elastic energy to push out of the 180° turn and transition into the reacceleration phase.

3.3.5 Summary of new perspectives

The multiple timing gate approach to assessing 5-0-5 COD performance may be of high utility to sports scientists and strength and conditioning coaches, though the reliability of this diagnostic protocol is currently unknown and requires further investigation. It is evident that 180° COD ability assessed via the modified 5-0-5 COD test using a total time, is somewhat correlated to concentric eccentric, isometric, and reactive strength (4, 63, 100, 110, 112, 207). It has been shown that high levels of eccentric strength are required to rapidly decelerate the body, however the effects of an eccentric only training program on COD performance is unclear. Eccentric strength was shown to have the strongest correlation to COD performance (207), which is important for the deceleration phase of the 5-0-5 COD test. Concentric strength is hypothesised to be related to the acceleration/first step quickness and reacceleration phases, while isometric strength is most associated with the change of direction phase. There is currently no COD test that can assess each of these COD phases individually. Developing a test that can isolate these phases, would provide insight into potential strengths and weaknesses of an athlete during 180° COD performance. One potential way to do this would be to add in two more sets of timing gates to the 5-0-5 test, as this would produce several split times for each section of the test.

3.4 Practical Application and Future Research Directions

The authors believe that there is scope to improve the diagnostic value of the modified 5-0-5 COD test, by segmenting the conventional total time used to quantify COD ability, into component times and motor qualities. As such, scientists and coaches can be more targeted with the feedback and programming to improve COD, and therefore, sporting performance. For example, an athlete may perform well in the deceleration phase of the 5-0-5 COD test, but may perform poorly in the acceleration phase, highlighting the need for improved concentric muscle strength. Prior to such an approach, a number of processes need to take place; namely: 1) it needs to be established whether each of the phases can be measured reliably; 2) determine if there is any collinearity between each of the phases (i.e., are they independent motor qualities); 3) establish the strength/power qualities that are important determinants of each phase; 4) investigate whether these qualities can be measured reliably and thereafter their predictive ability; and, 5) determine the exercise and programming considerations to improve these qualities.

CHAPTER 4 - SUB-PHASE ANALYSIS OF THE MODIFIED 5-0-5 TEST FOR BETTER CHANGE OF DIRECTION DIAGNOSTICS

This chapter comprises the following paper published in *The Journal of Sport and Exercise Science*.

Reference:

Ryan, C., Uthoff, A., McKenzie, C., & Cronin, J. (2021). Sub-phase analysis of the modified 5-0-5 test for better change of direction diagnostics. The Journal of Sport and Exercise Science, 5(5).

4.0 Prelude

In previous chapters, it has been intimated that the 5-0-5 COD test, albeit important, lacks diagnostic value as it only provides a measurement of total time. However, as discussed in Chapter 3, COD is a complex movement, made up of several different phases, i.e., acceleration, deceleration, COD, and reacceleration. In the previous chapter, the authors proposed a novel method of enhancing the diagnostic value of the modified 5-0-5 test, by adding in additional timing gates to isolate the sub-phases, however, whether accurate and reliable information can be captured using such an approach was unknown. The aim of Chapter 4 therefore, was to determine the reliability of this proposed test and determine the inter-relationship between the sub-phases and which sub-phases were best predictors of total time. If found reliable, practitioners could use this novel assessment to gain deeper insights into an athlete's strengths and weaknesses in relation to COD.

4.1 Introduction

The ability for an athlete to perform a change of direction (COD) is an important physical quality in many team sports, including, soccer (123), volleyball (78) and netball (40). For example, in netball, a player performs on average 64 COD manoeuvres (75), and a top class soccer player performs, on average, 726 changes of direction during a match (26). Due to this high volume of direction changes performed by athletes, it is important to have valid and reliable tests to measure an athlete's COD ability.

The modified 5-0-5 (beginning from a stationary start 0.5 m behind the first timing gate) COD test is one such test used to assess an athlete's ability to rapidly accelerate, decelerate, turn 180° and reaccelerate again. These physical qualities are important for most multidirectional sports (53). Traditionally, the modified 5-0-5 COD test uses one set of timing gates to assess an individual's ability to sprint 5 m, perform a 180° COD and sprint 5 m back through the timing gates. This test produces a total time (s) for the athlete's performance; however, this test does not provide insight into the performance of the different phases/qualities listed previously.

To provide more useful information to practitioners, it would be beneficial to have measures that differentiate between the different phases of the modified 5-0-5 COD test (acceleration, deceleration, 180° turn and reacceleration). Total time may give some insight into COD performance; however, it fails to provide an isolated measure of each phase. For example, an athlete may have great acceleration and poor 180° turn ability, but still produces a good total time. Knowing the contribution of each phase will provide higher levels of diagnostics to better inform COD speed development and programming. Similar research has been conducted by Forster and colleagues (73) for the pro-agility COD test with male high school athletes. The test was adapted, with the addition of timing gates 1 m from each COD line, enabling acceleration, deceleration, and COD performance to be isolated. The authors of this study reported acceptable absolute consistency (coefficient of variation [CV] <10%) for nearly all variables and 'poor' to 'good' relative consistency for all variables from days 1-2 and days 2-3 comparisons (intraclass correlation coefficient [ICC] = 0.13 to 0.86). The acceleration 2 and 4 split had the highest variability for both day 1-2 and 2-3, however the COD 1 split had the lowest relative consistency (ICC = 0.13). It is of importance to explore both absolute and relative consistency, to get a full understanding of a test's reliability (103). Similar procedures should be explored for the modified 5-0-5 COD test to provide greater diagnostic value.

If there is a high degree of shared variance between phases of the modified 5-0-5 COD test, then there is not a solid rationale for separately measuring these athletic qualities. Therefore, the first purpose of this study was to determine the strength of the relationship between the different sub-phases of the modified 5-0-5 COD test. If these sub-phases have a shared variance (R^2) lower than 50%, then the qualities are thought to be reasonably independent of each other (i.e., there is more unexplained variance than explained variance) and therefore it needs to be established whether these sub-phases can be measured accurately and consistently. Thus, quantifying the between session variability associated with the sup-phase analysis provided the second purpose of this article.

4.2 Methods

4.2.1 Experimental approach to the problem

Ten elite female netball athletes performed three maximal effort trials (each leg) of the modified 5-0-5 COD test, over three testing occasions in the athlete's pre-season, separated by seven days in this within subject repeated measures experimental design Timing lights were placed at 0, 2 and 4 m and the start line was placed 0.5 m back from the first timing gate, to accommodate for a forward lean and eliminate false triggering of the timing lights. This enabled five distinct sub-phases to be established in order to more accurately detect acceleration, deceleration, and COD performance. Shared variance was established via coefficients of determination. The variability of the sub-phases/qualities were quantified using CVs and ICCs.

4.2.2 Participants

Ten elite female netball athletes (age: 24.9 ± 5.0 yrs, height: 180.1 ± 6.5 cm, weight: 81.3 ± 15.0 kg) participated in this study. Athletes competed in the New Zealand netball premiership league and had a minimum of six years netball experience. Participants were required to be healthy and free of injury at the time of testing. All participants were provided with an information sheet and were required to fill out a written consent form prior to participating in this study. Participants were notified that they were free to withdraw from the study at any point. This research was approved by the Auckland University of Technology Ethics Committee (20/402).

4.2.3 Measures

Dual beam timing gates (Swift Performance Equipment, New South Wales, Australia) were used to quantify COD performance. Gates were set at 0, 2 and 4 m to isolate the phases of the 5-0-5 COD test (acceleration, deceleration, 180° turn and reacceleration). These distances were piloted, and the authors found that if the last timing gate was any closer to the turn line, then subjects body parts would prematurely break the timing gates. Timing gate height was set at 1 m, in approximate line with centre of mass. This set up produced five different splits, as well as total 5-0-5 COD performance time. These times corresponded to the different phases of the modified 5-0-5 COD test as outlined in Table 4.1.

4.2.4 Procedures

Testing was conducted on an indoor netball court. Athletes were instructed to wear the same clothing and footwear for all three sessions. The athletes perform the modified 5-0-5 test on a weekly basis as part of their normal programming and therefore did not require a familiarisation session. Testing was conducted seven days apart, at the same location and time of day. Each testing session was 40 minutes and athletes performed a standardised warm up consisting of lower body activation such as banded walks and squats, a series of different jumps (vertical and horizontal bilateral and unilateral countermovement jumps), dynamic flexibility of the hamstrings, quads, hips and calves, and progressive sprint (5, 10 and 20 m) and COD drills, building the intensity up to maximum effort.

For the modified 5-0-5 COD test, athletes were required to start 0.5 m back from the first timing gate. Athletes were instructed to sprint 5 m and touch their foot on or over the COD line, perform a 180° turn on a specific leg and sprint 5 m back through the first timing gate. Three trials within each testing session were performed on each leg. Three minutes of rest was provided between trials to limit any fatigue effects. Athletes were instructed to begin behind the start line in a two-point stance and could begin the test whenever they were ready. To ensure each athlete touched the line, the researchers observed each trial. If the athlete had a mistrial, they were given a retrial after three minutes of rest.

4.2.5 Statistical analysis

As there were no significant differences found between left and right COD splits and total time (p = 0.10 – 0.67), the data was pooled, and all analyses thereafter was performed on the averaged data. Outlier and normality analysis was implemented on the pooled data and means, and standard deviations were reported for all variables of interest, with 95% confidence limits (CL) and an alpha level of 0.05 used where appropriate. Pearson correlation coefficients were used to determine the strength of association between variables with data collected from session 3. A simplified version of Schober et al., (195) correlational conventions was used, negligible and weak (0-0.39), moderate (0.40-0.69) and strong and very strong (0.70-1.00). Coefficients of determination (R^2) were used to quantify shared variance. The authors used a 50% shared variance threshold to determine the independence of variables (12, 107, 238). Absolute consistency between sessions was quantified using CV, where measures less than or equal to 10% were deemed acceptable (226). The CV was derived from the typical error (s) of the log-transformed variable via the following formula: $CV = 100(e^{s} - 1)$. Relative consistency between sessions was determined using ICC using a two-way random average measures model (117). Classification of ICC was deemed as follows: 'very poor' (< 0.20), 'poor' (0.20 - 0.49), 'moderate (0.50 – 0.74), 'good' (0.75 – 0.90) or 'excellent' (> 0.90) (32). Statistical analysis was performed using IBM SPSS statistical software package (version 27.0; IBM Corporation, New York, USA).

Table 4.1: The different splits in the modified 5-0-5 COD test and the name and explanation of the sub-phase

Split	Name	Explanation	Quality
1	Acceleration	From start line to first timing gate (2 m)	Concentric first step quickness
2	Deceleration	From second timing gate to third timing gate (2 m)	Eccentric strength and SSC
3	180° turn	One step before and after the 180° turn. From third timing gate to turn line (2 m)	Lateral reactive strength (SSC) and isometric strength
4-5	Reacceleration	From third timing gate to finish (4 m)	Concentric strength and SSC
1-5	Total time	5-0-5 COD test total time (10 m)	All qualities

4.3 Results

The strength of association between each split for the modified 5-0-5 COD test are presented in the correlation matrix (Table 4.2). Correlations between variables ranged from 0.28 to 0.94. In terms of the relationship with total time, the 180° turn had the greatest shared variance (R^2= 88.4%) whereas the lowest shared variance was during the reacceleration phases (R^2= 42.2%). Correlations between sub-phases ranged from 0.28 to 0.83. The greatest shared variance between the sub-phases was 68.9% between deceleration and reacceleration 2 and was the only variable to explain more than 50% of shared variance between sub-phases. The lowest shared variance, (7.8%) was between reacceleration 1 and reacceleration 2.

Table 4.2: Pearson correlations (r) between the splits for the modified 5-0-5 COD test

	Acceleration	**Deceleration**	**180° Turn**	**Reacceleration 1**	**Reacceleration 2**	**Total Time**
Acceleration	1.0					
Deceleration	0.65*	1.0				
180° Turn	0.67*	0.59	1.0			
Reacceleration 1	0.38	0.34	0.57	1.0		
Reacceleration 2	0.50	0.83**	0.50	0.28	1.0	
Total Time	0.74*	0.80**	0.94**	0.65*	0.69*	1.0

Key: * $p<0.05$, ** $p<0.01$

The inter-session variability of split times and total time for the modified 5-0-5 COD test can be observed in Table 4.3. The average change in mean (0.35%) between days was 1.08% (days 2-1) and 1.43% (days 3-2). There appeared no systematic change between the variables, the largest change was observed between days 3-2 for the reacceleration 2 phase (-2.4%). In terms of absolute consistency, all CVs were less than 10% (1.1 – 6.6%) the greatest variability found in the 180° COD. With regards to rank-order consistency, all but one variable had ICC's greater than 0.77, the lowest relative consistency found in reacceleration 1.

Table 4.3: Inter-session variability of split times

Variable	Mean ± SD			% Change in mean (95% CL)		CV (95% CL)		ICC (95% CL)	
	Day 1	*Day 2*	*Day 3*	*Day 2-1*	*Day 3-2*	*Day 2-1*	*Day 3-2*	*Day 2-1*	*Day 3-2*
Acceleration	0.55 ± 0.03	0.55 ± 0.03	0.54 ± 0.02	-0.8 (-2.3 – 3.57)	-1.2 (-0.81 – 1.31)	1.5 (1.0 – 2.8)	2.5 (1.7 – 4.7)	0.94 (0.78 – 0.98)	0.82 (0.44 – 0.95)
Deceleration	0.51 ± 0.03	0.52 ± 0.04	0.51 ± 0.04	2.1 (-1.0 – 5.4)	-1.2 (-3.1 – 0.7)	3.1 (2.2 – 5.8)	1.9 (1.3 – 3.6)	0.84 (0.39 – 0.96)	0.95 (0.78 – 0.98)
180° Turn	0.63 ± 0.09	0.64 ± 0.08	0.64 ± 0.09	1.8 (-2.8 – 6.5)	-1.0 (-7.2 – 5.6)	4.6 (3.2 – 8.6)	6.6 (4.5 – 12.3)	0.90 (0.64 – 0.98)	0.78 (0.29 – 0.94)
Reacceleration 1	0.63 ± 0.03	0.64 ± 0.02	0.65 ± 0.05	0.8 (-2.2 – 3.9)	1.7 (-2.4 – 5.8)	3.0 (2.1 – 5.6)	4.1 (2.8 – 7.6)	0.57 (-0.09 – 0.88)	0.77 (0.26 – 0.94)
Reacceleration 2	0.43 ± 0.02	0.43 ± 0.03	0.42 ± 0.03	0.2 (-2.2 – 2.7)	-2.4 (-5.6 – 0.9)	2.4 (1.7 – 4.5)	3.3 (2.3 – 6.2)	0.83 (0.43 – 0.96)	0.78 (0.31 – 0.95)
Total Time	2.75 ± 0.14	2.77 ± 0.17	2.74 ± 0.17	0.8 (-0.7 – 2.2)	-1.1 (-2.2 – 0.0)	1.4 (1.0 – 2.6)	1.1 (0.8 – 2.0)	0.95 (0.79 – 0.99)	0.97 (0.88 – 0.99)

4.4 Discussion

The purpose of this study was to firstly, determine the strength of inter-relationship between the sub-phases of the modified 5-0-5 COD test, and to determine whether any of the sub-phases were better predictors of COD total time. Also, we wanted to quantify the inter-relationship between sub-phases to determine if they were relatively separate motor qualities. A secondary aim was to determine the variability of the sub-phase qualities. The main findings were: 1) the 180° had the greatest shared variance with total time (R^2= 88.4%); 2) only one of the correlations between sub-phases explained more than 50% of the shared variance (i.e. deceleration and reacceleration), indicating that these sub-phases are for the most part measuring relatively independent neuromuscular qualities; and, 3) in terms of percent change in the mean, absolute consistency and relative consistency, no systematic bias was observed and most of the measures very stable between testing occasions. Given these findings, it appears the modified 5-0-5 is highly reliable between sessions in elite female netball players.

An interesting finding was that 180° turn was the best predictor for total time, which indicates that having good COD ability is the main factor for producing a good modified 5-0-5 total time. Previously it had been suggested that an athlete with good linear speed, but poor COD ability could perform well in a traditional 5-0-5 COD test as their linear sprinting ability could mask any COD deficiencies (165), given the greater proportion of time linear sprinting in that test. It would seem from the results using elite netball female athletes that the modified 5-0-5 may be a truer measure of COD ability given the effects of linear speed seem of lesser magnitude.

From the inter-correlations between sub-phases, it is clear that each of the motor qualities were relatively independent of one another, and only one sub-phase explained more than 50% of the shared variance, indicating that each phase for the most part was in fact measuring relatively different neuromuscular capabilities. Reacceleration 2 and deceleration had the greatest shared variance between sub-phases (R^2= 68.8%). Interestingly, the lowest shared variance was found between reacceleration 1 and reacceleration 2 (R^2= 7.84%). This suggests that although these two sub-phases are both reacceleration, they are in fact measuring different qualities. The authors hypothesised that reacceleration 1 would require greater concentric strength, whereas reacceleration 2 would be relying on greater reactive strength. To the authors knowledge, this is the first study to perform a sub-phases analysis on the modified 5-0-5 COD test, therefore there is limited literature to compare results with.

A majority of the research on the variability of the modified 5-0-5 COD total time, has focused on within-session variability (216, 219), however this information is of limited use as it does not indicate whether the test is variable across testing occasions. Barber and colleagues (17), reported high relative within-session consistency (ICC= 0.97) for the modified 5-0-5 COD test, however they did not report absolute consistency. In this study, total modified 5-0-5 COD time was found to have excellent (ICC= 0.95 and 0.97) relative consistency and acceptable absolute consistency (CV= 1.4% and 1.1%), between days 2-1 and 3-1 respectively. These results were similar to previous research for this test (17, 79).

All sub-phases were found to have good to excellent relative consistency (ICC = 0.77 to 0.98) and acceptable absolute consistency (CVs < 5%), except for acceleration 1 that was found to have moderate (ICC = 0.57) relative consistency between days 2-1. To the authors knowledge, there is currently only one study that has attempted to isolate and determine the variability of different sub-phases for a COD test. Forster and colleagues (73), measured different components of COD performance during a pro-agility COD test, by including three sets of timing gates. Interestingly, this research reported acceleration 1 to be the only variable with acceptable relative and absolute consistency (ICC= 0.71 to 0.79, CV= 5.16 to 5.39%). It was suggested that this may be because reacceleration phases may be influenced by COD, as post-COD acceleration or reacceleration can be influenced by the body and force orientation (57). This may have been the case for this research, as the reacceleration 1 phase was shown to have the lowest absolute and relative consistency (CV = 3.0% and 4.1%, ICC = 0.57 and 0.77), however these values are still acceptable and considered reliable. There was very little systematic bias between sessions, however, it needs to be noted that the participants were elite athletes that performed the modified 5-0-5 test on a regular basis and did not require any familiarisation.

4.5 Conclusion and Practical Applications

It appears that the modified 5-0-5 COD test can successfully be split into sub-phases, and each sub-phase can be measured consistently using dual-beam timing gates. It is clear that these sub-phases are relatively independent qualities, and therefore should be measured as such. A key finding is that netball athletes of this study displayed similar between session total times and that players turning ability is the best predictor of total time. Although educated guesses can be made as to which neuromuscular qualities are most at play during these sub-phases, further research is needed to solidify this. Furthermore, readers should be cognizant that the findings of these results are specific to well-trained netball athletes, and more research is needed with different athletic populations. This advanced modified 5-0-5 COD diagnostic protocol can enable strength and conditioning coaches and sports scientists to reliably track sub-phase performance and identify areas of strengths and weakness of their athlete, thereby providing specific information related to athletes which can be used for training specificity. Intuitively this should improve COD performance, however, such a contention needs to be validated using longitudinal designs.

CHAPTER 5 - INERTIAL MEASUREMENT UNIT ANALYSIS FOR PROVIDING GREATER DIAGNOSTIC VALUE DURING THE MODIFIED 5-0-5 CHANGE OF DIRECTION TEST.

This chapter comprises the following paper published in *The Journal of Sport and Exercise Science*.

Reference:

Ryan, C., Uthoff, A., McKenzie, C., & Cronin, J. (2023). Inertial measurement unit analysis for providing greater diagnostic value during the modified 5-0-5 change of direction test. *The Journal of Sport and Exercise Science*, *7*, 54-61.

5.0 Prelude

A constant theme in previous chapters was that the 5-0-5 COD test lacks diagnostic value when only measuring total time. In the previous chapter, a modified 5-0-5 test with added timing gates was shown to be a reliable assessment with the potential to improve the diagnostic value of the test. As suggested in Chapter 3, advanced technologies such as inertial measurement units (IMU) may provide further diagnostic value beyond temporal metrics. Of interest was whether advanced IMU footpod technology would provide useful information, however, the accuracy and reliability of this technology for measuring COD performance was unknown. The aims of this chapter therefore were to firstly, determine the reliability of various IMU variables during a modified 5-0-5 COD test and secondly, determine the inter-relationship between the different IMU and timing light split variables. If found reliable, practitioners could use this novel technology to gain deeper insights into an athlete's kinematics during a modified 5-0-5 COD test.

5.1 Introduction

Change of direction (COD) movements are prevalent in both team and individual sports, and the ability to execute them effectively is considered crucial for achieving success in most sports (17, 157, 181, 212). COD tasks involve different phases such as acceleration, deceleration, turning/cutting and reacceleration, as described by Ryan and colleagues (178, 180). One common test that is used to measure 180° COD performance is the Modified 5-0-5 COD test, however most researchers only quantify performance with total time (17, 79, 214). A better understanding of the kinematics and kinetics during a COD movement, rather than just providing total time, would provide practitioners with a more comprehensive understanding of COD test performance and how it can be improved (164). Ryan and colleagues (179) have aimed to improve the diagnostic capabilities of the test to provide measures of the different phases, however more advanced technologies can complement this analysis.

Motion capture systems and force plates are considered the gold standard for movement analysis and are used to measure a suite of kinematic and kinetic variables, such as joint range of motion, movement velocities, step kinematics, magnitude and orientation of ground reaction forces, and speed of COD movements (143, 145). However, this equipment can be expensive and not easily applicable to field settings (3). Other technologies such as Optojump has been used to quantify ground contact time during 180° COD tasks, with authors reporting moderate to good reliability (Intraclass correlation coefficients [ICCs] = 0.52-0.89; coefficients of variation (CVs) = 10.0 - 10.6%) (45). Though this technology can be used in a field setting, it may be too expensive or impractical to incorporate into some team sport settings.

Inertial measurement units (IMU's) provide a portable and relatively inexpensive alternative to measuring and monitoring an athlete's performance, through the measurement of acceleration, position and orientation during practice and games (39). IMU may be a practical solution to measuring step kinematics, such as acceleration, deceleration, and ground contact time during in-sport movements such as 180° COD. Practitioners could use this information to guide their exercise prescription and improve athletic performance (3). Many IMU companies use a lease model, for example IMeasureU starts at $6600 USD per year, while Plantiga foot pods are $2000 USD per year. With IMU's becoming increasingly popular, it seems important to determine if IMU technology can reliably measure COD performance, both within and between sessions.

Several researchers have reported on the reliability of IMU's to quantify different aspects of COD performance (13, 19, 153). For example, Balloch and colleagues (13) determined the reliability of using IMU technology attached to the posterior trunk, at the upper thoracic vertebrae (T1-T5). They developed an algorithm that was able to automatically detect and record COD movements ranging from 45-180°. They reported a good reliability for all angles measured (CVs = 1.3 - 4.2%). Barreira and colleagues (19) investigated the reliability of a trunk-mounted (placed on thoracic spine) accelerometer to measure player load during a side cut movement. The authors reported moderate to high correlations between trials and acceptable limits of agreement (from 17- 41%). Though these researchers have reported reliable metrics for these IMU's, there appears to be two main limitations. Firstly, the location of the IMU's at the trunk may not give the best representation of the foot-ground interaction. IMU's placed on the trunk may move around due to the jarring associated with fast and explosive movements such as sprinting or changing direction. This could be overcome by using a foot-mounted IMU placed in the sole of the shoe since the location is at the interface of the foot and shoe, enabling it to capture the initial impact of the foot during contact with the ground (163). The second limitation of trunk located IMU's is data extraction and processing. Many of the IMU's used by researchers do not provide instant performance results and need extensive amounts of post-processing before the data can be interpreted. This may be a disadvantage for many strength and conditioning coaches that work in the field with individual and team sport athletes that would benefit from instantaneous feedback.

There are several commercially available IMU's that are placed on (shoelace mounted) or within the shoes (mid-arch of an insole in placed of a standard running shoe insole) (163). Many of these shoelace mounted and insole IMU's are equipped with a 6 axis IMU sensor (3 axis accelerometer and 3 axis gyroscope), allowing researchers to measure individual limb performance and differences across limbs. Additionally, many of these commercially available IMU's come with software that calculates a range of different variables such as player load, maximum speed, peak acceleration, peak deceleration, and ground contact time. With the evolving nature of sports science and athlete monitoring, practitioners need to ensure that the devices and calculation methods used within the software are providing reliable performance metrics that can be used in the field. To the authors knowledge, at the time of this research, there was no study that had determined the reliability of an IMU placed at the foot, for measuring COD performance metrics.

Many authors have highlighted the importance of deceleration and acceleration ability (97, 100, 180) and ground contact time at the turn during a 180° COD task (54). Therefore, it would seem important to be able to easily quantify these metrics during a COD task. Hence, the aim this study was to firstly, determine the inter-session reliability of the Plantiga Insole IMU for measuring peak acceleration, peak deceleration, maximum speed and ground contact time during a modified 5-0-5 COD test. Secondly, it would seem important to determine the strength of association between firstly the different IMU variables and secondly between the IMU variables and timed metrics investigated by Ryan and colleagues (179) previously. This will help determine whether these IMU variables can predict certain temporal aspects of performance or add further diagnostic value to this COD test. This will provide coaches with greater insight into athletes' performance capabilities and therefore become more targeted with programming and exercise prescription.

5.2 Methods

5.2.1 Experimental approach to the problem

Ten elite female netball athletes performed three maximal effort trials (each leg) of the modified 5-0-5 COD test, over three testing occasions, separated by seven days. In-shoe IMU's were fitted to each athlete and placed within their normal court shoes before the commencement of the warm-up. The variability of the COD performance was quantified using CVs and ICCs.

5.2.2 Participants

Ten elite female netball athletes (age: 24.9 ± 5.0 yrs, height: 180.1 ± 6.5 cm, weight: 81.3 ± 15.0 kg) participated in this study. Athletes competed in the New Zealand netball premiership league and had a minimum of six years netball experience. Participants were required to be healthy and free of injury at the time of testing. All participants were provided with an information sheet and were required to fill out a written consent form prior to participating in this study. Participants were notified that they were free to withdraw from the study at any time. This research was approved by the Auckland University of Technology Ethics Committee (20/402).

5.2.3 Equipment

5.2.3.1 Inertial measurement unit

Plantiga IMU's (Plantiga Technologies, Vancouver, Canada; sampling frequency 416 Hz) were used during this research. Plantiga insoles are 6-axis IMU's (triaxial accelerometer and triaxial gyroscope) and are placed under each mid-foot. Each IMU is small, durable (42 x 47 x 3.4 mm), and water and impact resistant (see Figure 5.1). These insoles were placed in the participants shoes prior to the warmup. Four different metrics were extracted from the IMU cloud and used for analysis. Maximum speed was the highest speed achieved over the course of the modified 5-0-5 test and was measured at the centre of body mass by calculating the average speed for each foot strike. The calculation was recalibrated each time each foot hits the ground, or experiences zero velocity. Peak acceleration and deceleration metrics were also extracted from the cloud and calculated from the rate of change of the speed. Lastly, ground contact time (GCT) of the plant foot at the time of the turn was extracted for each trial. GCT was calculated from foot strike to toe off, as detected by machine learning algorithms. Drift was accounted for with zero-velocity detection, wherein when the foot is stationary (i.e., on the ground) the signal is recalibrated for every step.

5.2.3.1 Timing lights

Dual beam timing gates (Swift Performance Equipment, New South Wales, Australia) were also used to quantify COD performance. Gates were set at 0, 2 and 4 m to isolate the phases of the 5-0-5 COD test (acceleration, deceleration, 180° turn and reacceleration), a method previously used by Ryan and colleagues (179). Timing gate height was set at 1 m, in approximate line with centre of mass. This set up produced five different splits, as well as a total 5-0-5 COD performance time. These times corresponded to the different phases of the modified 5-0-5 COD test as outlined in Figure 5.2. Once all of the trials were complete, the IMU data was uploaded into the Plantiga cloud and stored on-board for later analysis.

Figure 5.1. Plantiga IMU insoles

5.2.4 Procedures

Testing was conducted on an indoor netball court. Athletes were instructed to wear the same clothing and footwear for all three sessions. All athletes were performing the modified 5-0-5 COD test on a weekly basis as part of their normal programming, and therefore did not require a familiarisation session. Each testing session was performed exactly 7 days apart, at the same location and time of day. Each testing session was 40 minutes, which included a standardised warm up consisting of lower body activation such as banded walks and squats, vertical, horizontal (bilateral and unilateral) jumps, progressive sprints (5, 10 and 20 m) and COD drills, building the intensity up to max effort.

For the modified 5-0-5 COD test a modified set up was used as described by Ryan and colleagues (179). Athletes started 0.5 m behind the start line (i.e., first timing gate) in a two-point split stance, with their preferred foot forward and began the test whenever they were ready. To ensure each athlete touched the line, the researchers observed each trial. If the athlete had a mistrial, they were given a retrial after three minutes of rest. Athletes were instructed to sprint 5 m and touch their foot on the COD line, perform a 180° turn on a specific leg and sprint 5 m back through the first timing gate. Three trials within each testing session were performed on each leg. Three minutes of rest was provided between trials to limit any fatigue effects.

5.2.5 Statistical analysis

All statistical analysis was performed using IBM SPSS statistical software package (version 27.0; IBM Corporation, New York, USA). Outlier and normality analysis was implemented on the raw data and means, and standard deviations were reported for all variables of interest. Absolute consistency between trials and sessions was quantified using CVs, where measures less than or equal to 10% were deemed acceptable (124). Relative consistency between trials and sessions was determined using ICC, using a two-way random average measures model (117). Classification of ICC was deemed as follows: 'very poor' (< 0.20), 'poor' (0.20 - 0.49), 'moderate' (0.50 – 0.74), 'good' (0.75 – 0.90) or 'excellent' (> 0.90) (32). Once reliability had been determined, relative left and right leg variables were compared for all IMU and timing lights metrics via paired t-tests. No statistical difference was found between left and right leg performance for any of the variables (p = 0.14 – 0.76), therefore data was pooled and further analysed. Pearson correlation coefficients were used to determine the strength of association between IMU variables as well as timing light splits. A simplified version of Schober et al., (195) correlational conventions was used, negligible and weak (0-0.39), moderate (0.40-0.69) and strong and very strong (0.70-1.00). Coefficients of determination (R^2) were used to quantify shared variance. The authors used a 50% shared variance threshold to determine the independence of variables (12, 107, 238).

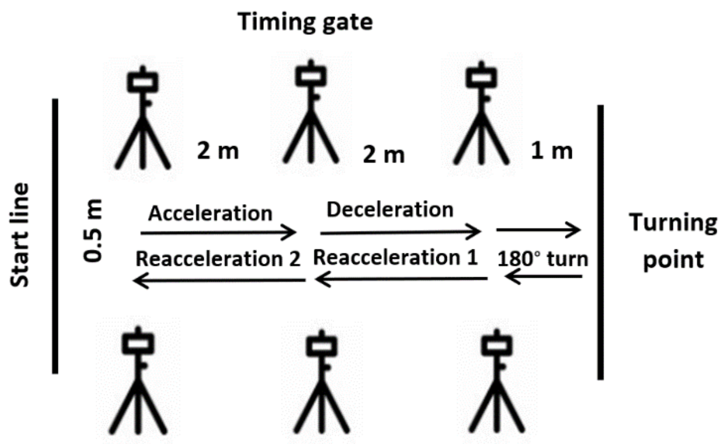

Figure 5.2: Modified 5-0-5 COD test with extra timing gates, producing five splits and total time.

5.3 Results

The inter-session variability of the IMU variables can be observed in Table 5.1. There appeared no systematic change between the variables, with the largest change observed between days 3-2 for the peak deceleration variable (-7.8%). In terms of absolute consistency, all CVs were less than 10% (1.8-9.5%) except for ground contact time left leg between days 2-1 (14.4%). With regards to relative consistency, all ICCs were greater than 0.80 (0.81 – 0.96), except for peak deceleration on the left leg turn, between days 2-1 (0.57).

A comprehensive matrix examining the strength of association between all right and left leg variables for each IMU, and timing light metric can be found in Supplementary Table 5.3 (Appendix D). There were no statistically significant differences observed between relative right and left leg IMU or timing light variables, therefore the pooled averages were used to examine associations between the variables. The strength of association between the pooled averages for each IMU and timing light variable are presented in the correlation matrix (Table 5.2). Correlations ranged from 0.04 to 0.95. With regards to total time measured with timing gates, the highest correlation and therefore biggest predictor of total time among IMU variables was found with peak acceleration (r = 0.95), and the lowest correlation was found with ground contact time (r = 0.04).

The biggest predictor for initial acceleration (split 1) and deceleration (split 2), was peak acceleration (r = -0.61, r = -0.86). Split 3, which is where the 180° turn occurs, had the strongest correlation with maximum speed (r = -0.89), while split 4 and 5 (reacceleration phases) had the strongest correlation with peak acceleration (r = -0.71 and 0.68, respectively).

The highest correlation found among IMU variables was between peak acceleration and maximum speed (r = 0.85), while the lowest correlation reported was between ground contact time and maximum speed (r = -0.10). Ground contact time had trivial to low correlations with all IMU and timing light variables (r = 0.23 – -0.44).

Table 5.1: Inter-session variability of IMU variables

Variable	Mean ± SD			% Change in mean (95% CL)		CV (95% CL)		ICC (95% CL)	
	Session 1	Session 2	Session 3	Session 2-1	Session 3-2	Session 2-1	Session 3-2	Session 2-1	Session 3-2
Max Speed (m/s) Left	5.3 ± 0.6	5.2 ± 0.6	5.2 ± 0.6	-2.8 (-6.2 – 0.7)	-1.7 (-5.2 – 1.8)	3.6 (2.4 – 6.6)	3.4 (2.3 – 6.5)	0.94 (0.74 – 0.98)	0.93 (0.71 – 0.99)
Max Speed (m/s) Right	5.3 ± 0.5	5.1 ± 0.6	5.1 ± 0.6	-3.6 (-6.3 - -0.9)	-0.9 (-3.9 – 2.3)	3.5 (2.5 – 5.8)	3.6 (2.6 – 6.2)	0.93 (0.79 – 0.98)	0.94 (0.80 – 0.98)
Peak Deceleration (m/s^2) Left	-2.6 ± 0.3	-2.5 ± 0.4	-2.4 ± 0.3	-1.3 (-8.4 – 6.4)	-7.8 (-12.0 - -3.5)	9.5 (6.9 – 16.2)	5.4 (3.8 – 9.4)	0.57 (0.07 – 0.84)	0.86 (0.59 – 0.95)
Peak Deceleration (m/s^2) Right	-2.6 ± 0.3	-2.5 ± 0.3	-2.4 ± 0.2	-4.0 (-7.8 – 0.1)	-5.0 (-8.3 - -1.5)	5.2 (3.7 – 8.6)	4.2 (3.0 – 7.2)	0.86 (0.56 – 0.95)	0.90 (0.66 – 0.97)
Peak Acceleration (m/s^2) Left	4.2 ± 0.3	4.0 ± 0.3	4.1 ± 0.4	-3.3 (-4.7 - -1.9)	-0.2 (-2.2 – 1.9)	1.8 (1.3 – 2.9)	2.3 (1.7 – 4.0)	0.96 (0.87 – 0.99)	0.94 (0.82 – 0.98)
Peak Acceleration (m/s^2) Right	4.1 ± 0.3	4.0 ± 0.2	4.0 ± 0.4	-0.8 (-2.3 – 0.8)	-0.1 (-2.5 – 2.3)	1.9 (1.4 – 3.2)	2.8 (2.0 – 4.9)	0.93 (0.79 – 0.98)	0.90 (0.68 – 0.97)
Ground Contact Time (ms) Left	344.5 ± 112.8	310.9 ± 59.6	306.3 ± 74.1	-7.0 (-16.7 – 3.9)	-4.9 (-11.0 – 1.6)	14.4 (10.3 – 24.7)	7.8 (5.5 – 13.7)	0.81 (0.51 – 0.94)	0.93 (0.78 – 0.98)
Ground Contact Time (ms) Left	337.5 ± 69.5	328.6 ± 71.1	301.3 ± 58.3	-2.8 (-7.6 – 2.2)	-6.5 (-12.3 - -0.4)	6.4 (4.6 – 10.7)	7.5 (5.4 – 13.2)	0.94 (0.82 – 0.98)	0.91 (0.73 – 0.97)

Key: CL = Confidence limit, m/s = metres per second, ms = milliseconds

Table 5.2: Correlation matrix between IMU variables and timing light variables during a modified 5-0-5 COD test

	Max Speed	Peak Decel	Peak Accel	GCT	505 Split 1	505 Split 2	505 Split 3	505 Split 4	505 Split 5	505 Total
Max Speed	1									
Peak Decel	0.65*	1								
Peak Accel	0.85**	0.54	1							
GCT	-0.10	0.24	-0.13	1						
505 Split 1	-0.57	-0.44	-0.61	-0.20	1					
505 Split 2	-0.59	-0.39	-0.86**	0.23	0.65*	1				
505 Split 3	-0.89**	-0.59	-0.81**	-0.04	0.68*	0.60	1			
505 Split 4	-0.69*	-0.55	-0.71*	-0.18	0.33	0.34	0.53	1		
505 Split 5	-0.57	-0.50	-0.68*	-0.44	0.39	0.82**	0.40	0.27	1	
505 Total	-0.91**	-0.64*	-0.95**	-0.04	0.74*	0.79**	0.94**	0.64*	0.60	1

Strong correlation (r = 0.7 to 1.0)
Moderate correlation (r = 0.4 to 0.69)
Weak correlation (r = 0.0 to 0.39)

Key: * = Correlation is significant at the 0.05 level, ** = Correlation is significant at the 0.01 level, accel = acceleration, decel = deceleration. GCT = ground contact time

5.4 Discussion

The aim of this study was to firstly, determine the inter-session reliability of the various IMU variables during a modified 5-0-5 COD test and secondly, determine the strength of inter-relationship between the different IMU and timing light variables. The main findings were: 1) there appeared to be no systematic change between the variables across days; 2) absolute consistency was acceptable for all variables, except for GCT on the left leg at the turn, between days 2-1 (14.4%) and all ICC's were greater than 0.80, with the exception of peak deceleration left; 3) no significant differences were observed between right and left leg variables, therefore the data was pooled to determine the strength of interrelationships; 4) the biggest predictor for total time measured with timing gates was peak acceleration (r = 0.95); and 5) Ground contact time had trivial to low correlations with all IMU and timing light variables (r = 0.04 – 0.44). It would seem that in a population of elite athletes, where biological variation is minimal, that the measures used are reliable and could be used for longitudinal monitoring. These key findings may be of importance to coaches and practitioners when considering how to assess COD performance for court-sport athletes.

To the authors knowledge, this is the first study to look at the reliability of firstly an insole IMU, as well as these specific variables during a modified 5-0-5 COD test. All variables were found to have good to excellent relative consistency (ICC = 0.81 to 0.96), except for peak deceleration on the left turn between days 2-1, which had moderate relative consistency (ICC = 0.57). In terms of absolute consistency, all variables had CVs less than 10%, with the exception of ground contact time left (CV = 14.5%). Previously, Balloch and colleagues (13) investigated the reliability of trunk-mounted IMU's to measure COD angles ranging from 45-180°, reporting similar reliability (CV = 1.3 – 4.2%). Barreira and colleagues (19) also investigated the use of a trunk-mounted IMU, however they were looking specifically at the reliability of tracking player load, during a COD task. They reported good to excellent reliability for player load (ICC = 0.83 – 0.95) and player load per minute (ICC = 0.80 – 0.92), which were similar to the results reported in the current study. Lastly, there was very little systematic bias between sessions in the current study, however it needs to be noted that the participants of this study were elite level athletes that performed the modified 5-0-5 test on a regular basis and did not require any familiarisation.

With regards to the strength of association, it is first important to compare the IMU variables against timing light variables, specifically total time, which is currently the most common piece of equipment and metric used to measure 5-0-5 COD performance (181). This comparison will provide insight into whether foot-mounted IMU's provide additional diagnostic information. Total time, measured with timing gates, had the highest correlation with peak acceleration (r = -0.95) explaining 90.3% of total time, which intuitively makes sense, as a majority of the modified 5-0-5 COD test is spent accelerating, firstly from the start point, and secondly out of the 180° turn. In other words, peak acceleration, measured with the IMU, appears to be the greatest predictor for total time during the modified 5-0-5 COD test. To the authors knowledge, no previous research has investigated the relationship between timing light variables and IMU variables. However, Jones and colleagues (110) previously investigated the correlation between the traditional 5-0-5 COD test and several other performance tests. The largest predictor for 5-0-5 time was sprint speed (r = 0.77), followed by eccentric flexor strength (r = 0.63). Eccentric flexor strength is thought important for decelerative ability and interestingly, had a similar relationship with total time, as seen in the current study with peak deceleration and total time (r = 0.64). Conversely, the lowest correlation reported for the total time measure, was with GCT (r = 0.04), explaining only 0.16% of total time. This is to be expected, as the GCT variable is only providing a small snapshot of what is occurring at the foot at the time of the 180° turn, whereas total time is providing a metric that represents the entirety of the test.

Previous research has determined the strength of association between the timing light phases (179), however to the authors knowledge, there is currently no research that has determined the strength of association between timing light phases and IMU variables. Several interesting observations were made in the current study with regards to the strength of association between timing light phases and IMU variables. Firstly, split 1 which can be defined as the initial acceleration had the strongest correlation with peak acceleration (*r* = 0.61), explaining 37.0% of the shared variance. This is a moderate correlation, and the shared variance was below 50%, indicating that these metrics are relatively independent of one another. Secondly, peak acceleration also had the largest correlation with split 2 (*r* = 0.86) explaining 74% of this split, which would be expected, as athletes are likely to be hitting their peak acceleration between split 1 and 2. Thirdly, split 3 has been previously identified as the 180° turn split (179), and one of the highest correlations between split times and IMU variables was reported between split 3 and maximum speed (*r* = 0.89), explaining 79% of the shared variance. These findings suggest one of two things. First, the higher the max speed reached during the test, the faster the time of the 180° turn split. Second, the faster the 180° turn split, the faster max speed reached during the test. The latter is likely the case, as athletes should be reaching their maximum speed during the end of the reacceleration phase of the test, and if an athlete performs the 180° turn well, this should set them up for a better reacceleration. When taking into consideration the population used in this study (elite athletes), this makes sense, as those reaching higher max speeds are likely having faster entry velocities coming into the turn and have the ability to decelerate quickly and effectively coming into the turn. It is also likely that these athletes have well developed reactive strength to push out of the turn and therefore also have fast exit velocities (149).

With regards to the relationship between the four IMU variables reported, peak acceleration and maximum speed had the strongest correlation (*r* = 0.85), with peak acceleration explaining 72.3% of maximum speed. This intuitively makes sense, as those athletes with greater peak acceleration, will usually reach the higher maximum speeds during the test. Conversely, GCT at the turn and maximum speed had the weakest relationship (*r* = -0.10), explaining only 1% of one another. This was to be expected, as GCT variable is measured at the time of the turn when the GCT will be the longest throughout the entire test, however the athlete has more steps to reaccelerate after the turn and achieve maximum speed (53). If average GCT was explored during the different phases such as acceleration, a stronger correlation would likely be observed. These results indicate that GCT is providing additional diagnostic information, as it had a weak relationship between both IMU variables and timing light variables (*r* = -0.44 - 0.23). It seems that GCT is an important variable to track with regards to COD performance, as it is thought that faster GCT result in better COD performance (53). This diagnostic information could provide practitioners with information regarding an athlete's reactive abilities when pushing out of the turn and inform further programming to minimise GCT and enhance an athlete's 180° turning ability. Peak deceleration also had moderate to low correlations with other IMU variables and timing light metrics (*r* = -0.64 – 0.59), suggesting that this IMU variable is providing additional diagnostic information that can be used by coaches and practitioners to further refine their exercise prescription.

Authors have detailed the importance of linear speed, deceleration and reacceleration during COD manoeuvres (180, 196). Specifically with the 5-0-5 COD test beginning with acceleration, then deceleration to a complete stop and reacceleration into the new direction (43), it would seem important to monitor these variables. The IMU insoles used in this study were found to provide a reliable way to measure acceleration, maximum speed, deceleration and ground contact time during a modified 5-0-5 COD test. Though some high correlations were reported between timing gate splits and IMU variables, it appears that most of the IMU variables are relatively independent (R^2 = <50%), therefore can be used in addition to timing gates, to increase the diagnostic value of the modified 5-0-5 COD test.

5.5 Conclusion, Limitations, and Practical Applications

It appears that an IMU mounted on the insole of a shoe can be used to reliably measure peak acceleration, peak deceleration, max speed and ground contact time during a modified 5-0-5 COD test. The information reported in this study provides coaches and practitioners with valuable information, for example, peak acceleration seems the biggest predictor for total 5-0-5 COD time. This information can help coaches become more specific with their programming. Additionally, a majority of the IMU variables are relatively independent to the timing light variables, therefore providing a rationale for the inclusion of this IMU insole to provide additional diagnostic information during a modified 5-0-5 COD test. The results of this study need to be interpreted with caution, as this study used elite level netball athletes, and therefore the results may be different for athletes of a different level, sport, or gender. Based off the results of the current study, it appears that use of the IMU insole can advance the diagnostic ability of the protocol for the modified 5-0-5 COD test. This advancement will enable coaches and practitioners to reliably track different metrics deemed important for COD performance. Additionally, it may help coaches identify areas of strengths and weakness for their athletes. These insights could assist with improving COD performance; however, such hypothesis needs to be validated using longitudinal designs. Lastly, it needs to be acknowledged that though the measurements were reliable, their validity, specifically during a 5-0-5 test is unknown, so coaches need to be aware of this when deciding whether to incorporate this tool into their assessments.

CHAPTER 6 - PROFILING CHANGE OF DIRECTION ABILITY USING SUB-PHASE 5-0-5 ANALYSIS

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

Reference:

Ryan, C., Uthoff, A., McKenzie, C., & Cronin, J. (2022). Profiling Change of Direction Ability Using Sub-Phase 5-0-5 Analysis. International Journal of Strength and Conditioning, 2(1).

6.0 Prelude

In the previous two chapters, it was found that the diagnostics provided during a modified 5-0-5 can be advanced with the addition of timing gates and IMU technology. This can allow coaches to gain deeper insight into their athletes COD performance. However, the utility of these new perspectives on COD assessment needs to be explored. Specifically, it is unknown whether the some of the component parts (acceleration, deceleration, etc) of COD are more important or comprise higher proportions of a COD test, which could lead to prioritisation of training. Furthermore, it would be interesting to understand whether an athlete's anthropometry (e.g. height, body mass) affects their ability to perform certain phases of the COD test. Finally, of interest is whether the data from the sub-phase analysis is of utility in identifying individual strength and weaknesses in a team sport environment. Given these ruminations the aims of this chapter were to, 1) understand what proportion of the test was actually spent changing direction, 2) determine whether anthropometry and positional differences influenced sub-phase performance and, 3) whether a sub-phase analysis could provide better diagnostic information to guide individualisation of programming. This information will provide coaches with a greater understanding of the 5-0-5 test and interpretation of the results.

6.1 Introduction

It is important for field and court sport athletes to have well developed change of direction (COD) ability, as it is considered essential for successful participation in many sports, as well as being one of the determining factors for elite level athletes (17, 77). There are a multitude of different assessments that can be used to map, monitor, and manage changes in COD performance. One test that is commonly used to measure 180° COD is the 5-0-5 COD test (167, 204, 219, 230). This COD test is a relatively simple test that is based on measuring the total time taken to complete a single 180° COD over a 15 m out and back course (traditional) (60) or a 5 m out and back course (modified) (79). Due to the simplicity and minimal equipment required to run this test, it has been adopted by numerous different sports (119, 142, 173, 192). However, a limitation to these tests is that only a total time is produced, providing limited diagnostic value on how athletes enter, perform a 180° turn and exit. Researchers have designed tests such as the COD deficit (166) and deceleration deficit (43), which aim to isolate the deceleration phase of the traditional 5-0-5 COD test. However, these protocols still do not provide information for the acceleration, 180° turn and reacceleration phases.

Alternatively, the 5-0-5 COD tests can be divided into sub-phases (i.e., acceleration, deceleration, 180° turn and reacceleration) to provide better diagnostic value and guide programming to better effect. One criticism of COD testing is that a large percentage of the current tests are spent linear sprinting, not directly assessing COD, thus any insight into COD ability is masked by the global measure of total time (165). Therefore, it would seem useful to understand the time spent in each phase and, most importantly, measure COD ability directly. Secondly, it is important to recognise that not all linear movement is the same. Athletes will accelerate, decelerate, and reaccelerate all within a single test (112). As such, these movement qualities have different neuromuscular requirements and therefore require different programming and training (89, 97). Such a contention is supported by the findings of Ryan et al., (179) who showed that acceleration, deceleration, 180° turn and reacceleration, were mostly independent motor qualities in elite female athletes, reporting that only one variable explained more than 50% of the shared variance between sub-phases.

The ability to change direction depends largely on sufficient braking capabilities to halt momentum (50). It could be hypothesised that players with greater body mass would have slower COD performance times as they face a greater neuromuscular challenge to decelerate and re-accelerate their body (momentum = mass x velocity) (100). This posit was substantiated by Hewit and colleagues (99), who highlighted that anthropometric measures contributed to COD performance. To the authors' knowledge there is currently no researcher that has investigated the effects of anthropometry on COD performance in elite female netball athletes. Previous researchers have shown differences in anthropometric measures between playing positions in netball (85, 220). Mid-court players are, on average, shorter (171 cm) and have a smaller body mass compared to circle defenders and shooters (177.5 cm). Therefore, it would be hypothesised that these mid-court players would have faster COD times (85, 220).

Given this information, the authors were interested in the potential insights a modified 5-0-5 test, divided into sub-phases (i.e., acceleration, deceleration, 180° turn and reacceleration), could provide. Of particular interest was to understand what proportion of the test was actually spent in changing direction, if anthropometry and positional differences influenced sub-phase performance, and whether a sub-phase analysis could provide better diagnostic information to guide individualisation of programming. It was hypothesised that the 180° turn sub-phase would be of the greatest duration, that heavier circle-end players and taller players would have slower times for all phases, and that the sub-phase ranking would enable better information to guide programming.

6.2 Methods

6.2.1 Experimental approach to the problem

Ten elite female netball athletes performed three maximal effort trials (each leg) of the modified 5-0-5 COD test, over three testing occasions, separated by seven days. Timing lights were placed at 0, 2 and 4 m and the start line was placed 0.5 m back from the first timing gate, to accommodate for a forward lean and eliminate false triggering of the timing lights. This enabled five distinct sub-phases to be established in order to more accurately detect acceleration, deceleration, and COD performance. The five sub-phases were then investigated in terms of percentage time spent in each phase, as well as the effects of anthropometry and position. A rank order analysis was also included as an exemplar on how to identify individualised player strengths and weaknesses.

6.2.2 Participants

Ten elite female netball athletes (age: 24.9 ± 5.0 yrs, height: 180.1 ± 6.5 cm, body mass: 81.3 ± 15.0 kg) participated in this study. Athletes competed in the New Zealand netball premiership league and had a minimum of six years netball experience. Participants were required to be healthy and free of injury at the time of testing. All participants were provided with an information sheet and were required to fill out a written consent form prior to participating in this study. Participants were notified that they were free to withdraw from the study at any point. This research was approved by the Auckland University of Technology Ethics Committee (20/402).

6.2.3 Procedures

Testing was conducted on an indoor netball court. For the modified 5-0-5 COD test, athletes were required to start in a two-point split-stance with their front foot 0.5 m back from the first timing gate. They were then instructed to sprint 5 m and touch their foot on the COD line, perform a 180° turn on a specific leg and sprint 5 m back through the first timing gate. All athletes completed a standardised warmup consisting of lower body activation such as banded walks and squats, a series of different jumps (vertical and horizontal bilateral and unilateral countermovement jumps), dynamic flexibility of the hamstrings, quads, hips and calves, and progressive sprint (5, 10 and 20 m) and COD drills, building the intensity up to maximum effort. After the warmup was completed, each athlete performed three modified 5-0-5 COD test trials on each leg. Three minutes of rest was provided between trials to limit any fatigue effects. To ensure each athlete touched the line, the researchers observed each trial. If the athlete had a mistrial, they were given a retrial after three minutes of rest. They were instructed to perform the test at maximal effort.

6.2.4 Equipment

Dual beam timing gates (Swift Performance Equipment, New South Wales, Australia) were used to quantify COD performance. Gates were set at 0, 2 and 4 m from the start line to assess acceleration, deceleration, 180° turn and reacceleration phases of the 5-0-5 COD test. Timing gate height was set at 1 m, in approximate line with centre of mass. This set up produced five different splits, as well as a total 5-0-5 COD performance time. These times corresponded to the different phases of the 5-0-5 COD test as shown in Figure 6.1.

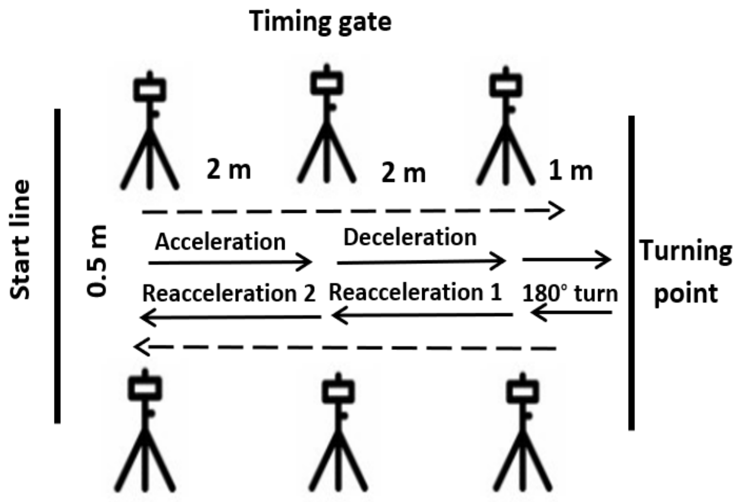

Figure 6.1: Set up and phases for the modified 5-0-5 change of direction test

6.2.5 Statistical analysis

No significant differences were found between left and right COD times, and so the data was pooled, and all analyses thereafter was performed on the averaged data. Outlier and normality analysis was implemented on the pooled data and means, and standard deviations were reported for all variables of interest, with 95% confidence limits (CL) used where appropriate. The median body mass and height were used to group players according to anthropometry, whereas the players position dictated the group they fell within for an inter-group analysis. Independent t-tests were used to assess statistical significance ($p<0.05$) between anthropometry (body mass and height), player position and performance of the sub-phases. Phase ratios were calculated using the formula, phase time/total time *100. Rank-order analysis was also conducted to provide a visual evaluation of rankings of the dependent variables of interest. Statistical analysis was performed using IBM SPSS statistical software package (version 27.0; IBM Corporation, New York, USA). Hedges's g effect size was calculated on the mean change between groups and interpreted using the follow criteria; Small effect = 0.2, medium effect = 0.5 and, large effect = 0.8 (93).

6.3 Results

The average times for each sub-phase and average percentage of time spent in that phase (~15 to 23%) can be observed in Table 6.1. The highest percentage of time was spent during the 180° turn and the reacceleration 1 phases (~23%), with the lowest percentage of time being spent during the reacceleration 2 phase (15.5%).

Table 6.1: Average time and percentage of total time for each sub-phase of the modified 5-0-5 COD test

Total time	
Average time ± SD (s)	2.75 ± 0.16
Range (s)	2.55 – 3.03
Percentage (%)	100
Acceleration	
Average time ± SD (s)	0.55 ± 0.03
Range (s)	0.47 – 0.79
Percentage (%)	19.9
Deceleration	
Average time ± SD (s)	0.51 ± 0.03
Range (s)	0.47 – 0.56
Percentage (%)	18.7
180° turn	
Average time ± SD (s)	0.64 ± 0.08
Range (s)	0.53 – 0.79
Percentage (%)	23.1
Reacceleration 1	
Average time ± SD (s)	0.64 ± 0.03
Range (s)	0.60 – 0.71
Percentage (%)	23.3
Reacceleration 2	
Average time ± SD (s)	0.43 ± 0.02
Range (s)	0.39 – 0.46
Percentage (%)	15.5

Sub-phase differences as a function of height, body mass, and position are shown in Table 6.2. Significant differences were found between heavier (>74 kg) and lighter (<74 kg) athletes for deceleration, 180° turn, reacceleration 2 and total time (7.32 - 17.14%; g = 1.90 – 2.54). However, while body mass was not found to significantly influence acceleration and reacceleration 1 sub-phases, there was a very large effect for the reacceleration 1 phase. No significant differences were found between taller (>182 cm) and shorter (<182 cm) players for any of the variables (1.82 - 3.08%). In terms of the positional analysis, only one significant difference was found between circle players and mid-court players during the reacceleration 1 phase (8.20%; g = 2.24). Additionally, though no significant differences were identified between positions for deceleration and total time, large effects were observed in favour of the mid-court athletes.

Table 6.2: Sub-phase differences as a function of height, body mass and position

Variable	Mean ± SD		P Value	Difference (%)	Effect Size
Height	**> 182 cm (184 ± 4.44)**	**<182 cm (178.2 ± 4.38)**			
Acceleration	0.54 ± 0.03	0.55 ± 0.03	0.70	1.82	0.33
Deceleration	0.52 ± 0.03	0.51 ± 0.04	0.70	1.92	0.28
180° Turn	0.65 ± 0.09	0.63 ± 0.09	0.71	3.08	0.22
Reacceleration 1	0.65 ± 0.03	0.63 ± 0.03	0.20	3.08	0.67
Reacceleration 2	0.43 ± 0.02	0.42 ± 0.03	0.69	2.38	0.39
Total Time	2.79 ± 0.15	2.72 ± 0.17	0.50	2.51	0.44
Body mass	**>74kgs (71.54 ± 1.56)**	**<74kgs (88.25 ± 40.73)**			
Acceleration	0.56 ± 0.35	0.54 ± 0.01	0.20	3.57	0.08
Deceleration	0.54 ± 0.02	0.49 ± 0.03	0.02*	9.26	1.96
180° Turn	0.70 ± 0.07	0.58 ± 0.03	0.01**	17.14	2.23
Reacceleration 1	0.66 ± 0.04	0.62 ± 0.02	0.10	6.45	1.26
Reacceleration 2	0.44 ± 0.01	0.41 ± 0.02	0.02*	7.32	1.90
Total Time	2.88 ± 0.12	2.63 ± 0.07	0.00**	8.68	2.54
Position	**Circle Defence/Attack**	**Mid-Court**			
Acceleration	0.55 ± 0.03	0.54 ± 0.01	0.45	1.85	0.45
Deceleration	0.52 ± 0.03	0.49 ± 0.03	0.24	6.12	1.00
180° Turn	0.66 ± 0.08	0.61 ± 0.08	0.43	8.20	0.63
Reacceleration 1	0.66 ± 0.03	0.61 ± 0.01	0.04*	8.20	2.24
Reacceleration 2	0.43 ± 0.02	0.42 ± 0.02	0.21	2.38	0.5
Total Time	2.81 ± 0.15	2.67 ± 0.15	0.18	5.24	0.93

Key: * $p < 0.05$, ** $p < 0.001$

The rank order for each of the athletes for each of the sub-phases can be observed in Table 6.3. The table has been colour coded to show the strength and weaknesses of each athlete, as determined by their sub-phase ranking being ± 2 ranks from their total time rank. For example, Athlete 1 had the fastest total time, however deceleration and re-acceleration have been identified as areas of poorer performance.

Table 6.3: Rank order table for total time and each sub-phase for the modified 5-0-5 COD test

	Total Time	Acceleration	Deceleration	180° turn	Reacceleration 1	Reacceleration 2
Athlete 1	1	2	4	1	4	1
Athlete 2	2	2	2	3	1	3
Athlete 3	3	5	1	3	6	2
Athlete 4	4	6	3	5	2	4
Athlete 5	5	1	6	6	3	8
Athlete 6	6	6	7	2	5	7
Athlete 7	7	2	5	8	9	5
Athlete 8	8	8	8	9	3	8
Athlete 9	9	10	10	7	8	10
Athlete 10	10	9	8	10	7	5

Key: Red = 2 positions below total time ranking, Green = 2 positions above total time ranking

6.4 Discussion

Providing better diagnostic information to guide programming in a more targeted manner was the primary purpose of this study. The main findings were: 1) the majority of time was spent during the 180° turn and reacceleration 1 sub-phases (~23%); 2) there were significant differences and very large effects between heavier and lighter athletes for three out of five sub-phases and total 5-0-5 COD time; and, 3) although athletes may produce a good total time, a sub-phase ranking analysis may provide diagnostic information to guide better and more targeted COD training.

Approximately 23% of the total time for the modified 5-0-5 COD test is spent actually changing direction. Previous research by Ryan et al., (2021) concluded that the 180° turn was the best predictor for total time (r= 0.94), which intuitively makes sense if the majority of the time is spent during this phase. Interestingly, a similar amount of time was spent in the reacceleration 1 phase. This may be due to the fact that athletes need to regain momentum after virtually coming to a stop to perform the 180° turning movement. These results differ to those found for the traditional 5-0-5 COD test. Nimphius and colleagues (166) reported that approximately 31% of the time was actually spent changing direction, however, this was calculated via the COD deficit. The COD deficit has been defined as a practical measure to isolate COD ability independent of sprint speed (165), however the authors feel that by subtracting an athlete's 10 m time from their 5-0-5 COD time does not provide insight into 180° COD ability, as the COD deficit does not account for deceleration and reacceleration out of the turn. Possible reasons for this 8% difference between findings could be; 1) the entry velocity going in to the 180° turn would likely be higher during the traditional 5-0-5 COD test, as they have an initial 15 m before having to perform the turn, requiring more time to come to a stop and change direction, or 2) the COD deficit method still includes the deceleration and reacceleration phases. Therefore, a sub-phase approach, such as the one used in this study may be more suitable for isolating COD ability.

It has been proposed that anthropometry could have a potential effect on COD (31). This study found that athletes with a greater body mass (>74 kgs) were significantly slower during the deceleration, 180° turn, reacceleration 2 split, and total time, compared to athletes with a lower body mass (<74 kgs). Larger players have greater momentum (mass x velocity) and therefore require greater eccentric braking strength to decelerate, turn and reaccelerate. These players are disadvantaged within tests that require athletes to essentially come to a stop and change direction. Several studies have reported that body composition (i.e., body mass and percentage of body fat) affects sprint and COD performance (9, 28, 41, 170, 221). However, one limitation of this study is that fat and lean mass was not measured, only body mass. It appears from the results of this study, as well as previous that of previous researchers, that it is ideal for an athlete to have a low amount of fat mass as a higher fat mass hinders sport performance (127). One of the simplest ways an athlete can improve their performance during these tests, as well as sporting performance, is to either improve their relative force capability or decrease their mass, or more specifically their fat mass, however this needs to be in a controlled and safe manner that does not affect performance (physical, cognitive etc.,) or overall health and wellbeing of the player.

In the initial hypothesis, the authors thought that taller players would produce significantly slower sub-phase and total times during the modified 5-0-5 COD test compared to shorter players, due to taller players usually having larger body mass. Interestingly, no significant differences were found between taller and shorter players for any of the sub-phases or total time.

The ability to change direction rapidly is a requirement for all netball positions (210). Interestingly, only the reacceleration 1 sub-phase was found to differ significantly between circle defence/attack players and mid-court players. This may be because mid-court athletes are more frequently performing COD manoeuvre before quickly accelerating in another direction (210). Although this is the first study to analyse the five different sub-phases of the modified 5-0-5 COD test, previous researchers have reported significant differences between mid-court athletes and circle defence/shooters for total 5-0-5 COD time (85). However, these findings are unsupported by this study. The differences in findings may be due to a range of reasons, such as heterogeneous player levels, number of participants, methods and statistical analysis. It should be noted that the traditional 5-0-5 COD test was used, rather than the modified 5-0-5 COD test. These different factors may play a significant role in the incongruent results from each study.

The sub-phase rank order table (Table 6.3) was used as an exemplar of how to identify potential strengths and weaknesses in players. The table highlights that Athlete 1 had the fastest total time and the fastest 180° turn time, which supports the finding that the 180° turn time was the greatest predictor of total time (Ryan et al., 2021). This approach to presenting data may also provide insight into the individualized areas that athletes could work on to improve their COD time. For example, Athletes 3 and 4 could benefit from an acceleration focus, whereas Athletes 1, 3 and 7 could benefit from a re-acceleration focus to training. This is not to say that training cannot be initiated in other areas as well. Furthermore, the training within each phase can have different foci e.g. physical-anthropometric, technical, and/or neuromuscular qualities. All athletes would benefit from reducing fat mass as much as practically possible for all sub-phases, but thereafter the sub-phases have specific technical, and strength demands.

6.5 Practical Applications

To the authors' knowledge, at the time of this study, no other research had determined the percentage of each sub-phase for the modified 5-0-5 COD test, as well as presented athlete data in a rank order table to identify areas that could be improved through targeted programming. It is apparent from this analysis that majority of the 5-0-5 COD test is spent in linear motion (i.e., acceleration, deceleration and reacceleration) and not changing direction (~23% of total time). Therefore, the sub-phase analysis is critical in isolating an athlete's COD ability. Furthermore, not all linear motion has similar technique and neuromuscular demands e.g., acceleration and deceleration. Once more the sub-phase analysis is important to measure, map, and monitor the changes in these qualities. By taking such an approach, provides the practitioner with higher level diagnostics, which can inform programming in a more granular manner. Principles of individualisation and specificity are more easily achieved with such an approach. It is evident that body mass does affect a player's ability to perform a 180° COD, with heavier players producing significantly slower times during three of the sub-phases, and the total time. Given acceleration is a function of force and mass (a = f/m), coaches can focus on improving accelerative ability by either increasing force capability (in particular, horizontal accelerative and decelerative force capability) and/or decrease fat mass. Lastly, the use of rank order tables for presenting performance times for a sub-phase approach during the 5-0-5 COD test can provide practitioners with insight into an athlete's different strengths and weaknesses. This method of presenting data enables coaches to develop more targeted programming to improve COD performance. The results from this study should be interpreted with caution, as this sample size and population is very specific to elite female netball athletes. Future research should aim to replicate the methodologies used in this current study, within other sports, populations, and sporting level.

CHAPTER 7 - THE ACUTE EFFECTS OF WEARABLE RESISTANCE PLACEMENT ON CHANGE OF DIRECTION PERFORMANCE IN ELITE NETBALL PLAYERS

This chapter comprises the following paper published in *European Journal of Sport Science.*

Reference:

Ryan, C., Uthoff, A., McKenzie, C., & Cronin, J. (2024). The acute effect of wearable resistance placement on change of direction performance in elite netball players. *European Journal of Sport Science*, 24(3), 302-311.

7.0 Prelude

In Chapter 1, WR was introduced as a tool for specific training, however there was limited research available on its utility for the training of COD performance. Over the previous chapters, the accuracy, reliability and utility of a novel modified 5-0-5 assessment have been established. With the enhanced granularity of the 5-0-5 COD test divided into the four phases of interest is if WR will influence each of the phases in a different manner. To establish this, an acute understanding of the effects of WR on the different sub-phases is the logical next step, prior to a training study. Therefore, the aim of this chapter was to utilise the advanced diagnostic protocol of the 5-0-5 COD test, to determine the acute effects of upper and lower limb WR on COD performance in elite level athletes. If limb-loaded WR is shown to provide an acute overload, this could provide coaches with a novel training tool for training and overloading different aspects of COD movement.

7.1 Introduction

Many team sports such as soccer, netball, and rugby league, are characterised by high-intensity movements like sprinting, rapid acceleration, deceleration, jumping and changing direction (17, 50, 213). Of these athletic movements, change of direction (COD) ability is considered one of the most essential for successful participation and performance in overground team sports (58, 166). Netball is played on a 30.5-m by 15.25-m court, divided into equal thirds. Different playing positions are restricted to certain areas of the court, with some athletes (e.g., goal shoot and goal keep) only having a small space to move in. Netball is a sport characterised by sharp changes of direction to break free from an opponent in order to receive the ball (208). During elite netball matches, athletes can perform up to 63 ± 7.6 COD manoeuvres during a 60 minute match (75), thus it would seem important for these athletes to have good COD ability and speed.

Previously, different training methods have been used in an attempt to enhance COD performance (186). The most commonly used training methods are plyometric (ES = 0.60 - 3.50) (8, 27, 109), traditional resistance (ES = 0.26 – 1.94) (7, 88, 116), and combination training (ES = 0.41 – 0.66) (61, 175). These training methods have shown a potential positive effect upon COD performance (64), however these researchers only reported the training effects on total time, and thus it is unknown which underlying sub-phases of completion time actually improved. Furthermore, the majority of the subjects were of young chronological age or low training age, therefore, more experienced athletes may require greater specificity and individualisation included in their strength and conditioning program to elicit a positive effect in COD performance (241). Some of the limitations of gym-based trainings are that many of the exercises are performed bilaterally and are vertically orientated, however movements such as sprinting and COD are primarily unilateral movements which require vertical, horizontal, and lateral force production (52). Implicit in the principle of specificity is that adaptations are specific to the nature of the training stress (237). Because COD is a complex movement that requires a combination of accelerative, decelerative and direction change ability, a more movement specific approach may be of greater benefit compared to more traditional approaches such as plyometrics or resistance training.

One training method that allows for specific transference to occur is wearable resistance training (WRT). WRT involves an external load being applied to segments of the body during movement and is an example of the application of the concept of training specificity (52). Wearable resistance involves the use of relatively light loads (1-5% body mass) attached to wearable garments such as a vest to overload linear ground reaction forces, or distal segments of the body such as the shank and forearm, to overload rotational kinetics during sport-specific movements such as sprinting or COD (128, 130). Greater rotational kinetics may increase strength across the kinetic chain, and thereby improve sporting actions which require sequencing of multiple body segments, such as acceleration, deceleration, and COD. To determine whether this training technique can be used longitudinally to improve COD performance, the acute effects of this loading strategy must be determined.

Rydså and colleagues (186) examined the acute effect of different lower limb WR placements and various load on COD ability in male soccer players. The COD test consisted of 90° and 45° split times. The authors reported a large effect for the different WR placements (ES = 1.4 – 2.0), with shank loading producing a longer total time and split times compared to thigh loading across all loading strategies. The largest total time significant ($p < 0.05$) difference was reported for 3 and 5% of body mass loading for shank and thigh, respectively (185). Li and colleagues (122), investigated the acute effects to COD performance during a 45° cut manoeuvre, in male soccer athletes, when an additional 5% body mass was attached to the torso. No significant differences between loaded and unloaded conditions in COD angle, approach speed, braking time, propulsive time, contact time and COD completion time were reported. A small increase in kinetics such as relative peak vertical propulsive ground reaction force (GRF) ($p = 0.11$, ES = 0.41) and relative peak braking GRF force ($p = 0.22$, ES = 0.38), were reported, which may be important kinetic stimuli for potential COD adaptation. To the authors knowledge there is no research that focuses on the acute effects of WR on COD performance in female athletes or netball athletes. Furthermore, researchers have focused on the effects of lower body and trunk loading on COD performance, however it has been reported that forearm loading provides a movement specific overload during sprinting (135, 227) and therefore may potentially provide a specific overload during COD tasks.

Therefore, the aim of this research was to determine the acute effects of forearm loading versus shank loading on COD performance in elite female netball athletes.

7.2 Methods

7.2.1 Experimental approach to the problem

A cross-sectional within-subject repeated measures design was used to determine the acute effects of WR on the kinematics during a modified 5-0-5 COD test. Subjects performed the modified 5-0-5 COD test as fast as possible (3 trials on each leg), under three different conditions in a randomised order. The three conditions consisted of; 1) shank loaded wearable resistance (WRs), with 1% body mass attached to each limb, 2) forearm loaded wearable resistance (WRf), with 1% body mass attached to each forearm and 3) no load (NL).

7.2.2 Subjects

Ten elite female netball athletes (age: 24.9 ± 5.0 yrs, height: 180.1 ± 6.5 cm, weight: 81.3 ± 15.0 kg) participated in this study. Athletes competed in the New Zealand netball premiership league and had a minimum of six years netball experience. Participants were required to be healthy and free of injury at the time of testing. All participants were provided with an information sheet and were required to fill out a written consent form prior to participating in this study. Participants were notified that they were free to withdraw from the study at any time.

7.2.3 Procedures

Prior to all testing sessions, subjects performed a 15-minute standardised warm up, consisting of lower body activation such as banded walks and squats, vertical and horizontal (bilateral and unilateral) jumps, progressive sprints (5, 10 and 20 m) and COD drills, building the intensity up to maximum effort. Athletes were familiar with the modified 5-0-5 COD test, as they perform this on a regular basis as part of their in-season training. For the modified 5-0-5 COD test, a modified set up was used, described by Ryan and colleagues (179). 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. Three trials were performed on each leg for the 180° turn. Three minutes of passive rest was provided between trials to limit the effects of fatigue. If an athlete had a mistrial, they were given a retrial after three minutes of rest. The same procedure was repeated for all three testing sessions and conditions. One condition was randomly assigned to each subject each session. Sessions were exactly 7-days apart and were held at the same indoor facility, at the same time of day. Participants wore the exact same clothing and shoes during each session to minimise changes in performance due to these factors.

7.2.4 Equipment

7.2.4.1 Exogen wearable resistance

For the WR shank loading, subjects were fitted with a pair of leg sleeves (Lila™, Sportboleh Sdh Bhd, Kuala Lumpur, Malaysia). The researcher loaded each subject with 1% of body mass (650 – 850 g) to each limb using fusiform shaped loads of 50, 100, 200, and 300 g, which were attached to the garments via Velcro backing. Loading was calculated to the nearest 50 g. Loads were placed from most proximal to distal on the shank. The first load was attached vertically with the heaviest part placed anteriorly on the leg, while the next load was placed the opposite way (see Figure 8.1A). A similar loading configuration was used for the forearm loading condition (see Figure 8.1B). The loads were required to be placed vertically to ensure the full load could fit onto the athlete's shank and forearm.

7.2.4.2 Inertial measurement unit

Plantiga IMU's (Plantiga Technologies, Vancouver, Canada; sampling frequency 416 Hz) were used to quantify the acute effects of different WR loading strategies on 5-0-5 COD performance. Plantiga insoles include 6-axis IMU's (triaxial accelerometer and triaxial gyroscope) that are placed under each mid-foot. Each IMU is small, durable (42 x 47 x 3.4 mm), and water and impact resistant. These insoles were fitted and placed in the participants shoes prior to the warmup. Data was only collected during the modified 5-0-5 test via the Plantiga cloud accessed via a computer. Four different metrics were extracted from the IMU cloud and used for analysis. These metrics are calculated via the Plantiga software and have been reported to be reliable during a modified 5-0-5 COD test (ICC = 0.86 – 0.94, CV's = 2.3 – 7.8%) (182). Maximum speed was the highest speed achieved over the course of the modified 5-0-5 test and was measured at the centre of body mass by calculating the average speed for each foot strike. The calculation was recalibrated each time each foot hits the ground, or experiences zero velocity. Peak acceleration and deceleration metrics were also extracted from the cloud and calculated from the rate of change of the speed. Lastly, ground contact time (GCT) of the plant foot at the time of the turn was extracted for each trial. GCT was calculated from foot strike to toe off, as detected by machine learning algorithms. Drift was accounted for with zero-velocity detection, wherein when the foot is stationary (i.e., on the ground) the signal is recalibrated for every step.

Figure 7.1: Illustration of 1% body mass loading with shank and forearm wearable resistance for 70kg netball player

7.2.4.3 Timing lights

Dual beam timing gates (Swift Performance Equipment, New South Wales, Australia) were also used to quantify COD performance. Gates were set at 0, 2 and 4 m to isolate the phases of the 5-0-5 COD test (acceleration, deceleration, 180° turn and reacceleration), a method previously used by Ryan and colleagues (179). Timing gate height was set at 1 m, in approximate line with centre of mass. This set up produced five different splits, as well as a total 5-0-5 COD performance time. These times corresponded to the different phases of the modified 5-0-5 COD test as previously described by Ryan and colleagues (179).

7.2.4 Statistical analysis

All statistical analyses were performed using IBM SPSS statistical software package (version 27.0; IBM Corporation, New York, USA). Data was presented as mean ± standard deviation (SD). Normal distribution of the data was checked using the Shapiro Wilk statistic. Preliminary analysis was done on no load condition between left and right legs, using a paired samples T-test. There were no significant differences between left and right leg data, therefore data was pooled for further analysis. A one-way repeated measures ANOVA with a Greenhouse-Geisser correction was used to determine the statistical differences in timing light and IMU variables between conditions. If significant differences were detected, post hoc comparisons with Bonferroni corrections were applied to determine where the differences occurred. 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 = 0.5-0.79, large effect = ≥ 0.8 (44). The smallest worthwhile individual change (SWC), moderate worthwhile change (MWC) and largest worthwhile change (LWC) was calculated on the pooled SD of the no load condition and converted to a percentage for each performance variable, where changes were deemed small (0.2 x SD), moderate (0.6 x SD), or large (1.2 x SD) (104).

7.3 Results

Descriptive performance for timing light variables under the different loading conditions and their comparisons are presented in Table 7.1. Total time was found to be significantly longer with a moderate effect (0.04 s; 1.45%; ES = 0.22 – 0.25) for both the WR conditions, as compared to the no load condition. The difference in total times were most likely due to significantly longer times ($p < 0.05$) with small to medium effects for acceleration (split 1) and deceleration (split 2) for shank loading (0.02 - 0.03 s; 3.85 - 5.50%; ES = 0.47 – 0.79) and acceleration (split 1) for the forearm loading. (0.02 s; 3.70%; ES = 0.67). No significant between WR conditions differences were observed, except for deceleration (split 2) which had a small yet significant effect (0.02 s; 3.78%; ES = 0.44). No significant differences were observed during COD phase (split 3) between loading conditions, however a small effect was observed for forearm loading compared to no load (0.02 s; 3.17%; ES = -0.27). Furthermore, no significant differences were reported between conditions for reacceleration (splits 4-5).

In terms of the IMU variables (see Table 7.1) it appears that the shank loading, and forearm loading had fairly similar effects on the variables of interest. There were small to moderate significant ($p < 0.01$) differences between no load and WR conditions for maximum speed and acceleration (WRs = 4.46 - 6.84%, ES = 0.60 and WRf = 3.20 - 5.84% and ES = 0.37 – 0.51). It appears that shank loading had a larger effect (ES = 0.60) on acceleration whereas forearm loading had a larger influence on peak deceleration (ES = 0.82) compared to NL. Once more no significant differences between WR conditions were observed.

Figures 8.2 and 8.3 provide graphical references illustrating the individual percentage changes relative to the SWC detected for each loaded condition, compared to NL. As can be observed, 60% of the athletes were above the SWC for total time for both shank loading and forearm loading conditions. Similar patterns can be seen for acceleration (split 1) and reacceleration (split 5) where 70-80% of athletes were above the SWC. It was observed that 80% of athletes were above the SWC for shank loading during deceleration (split 2), while only 30% were for forearm loading. In terms of IMU variables, 90-100% of athletes were above the SWC for maximum speed and peak acceleration, while 80% of athletes were above the SWC for peak deceleration for both loading conditions.

Table 7.1: Acute differences between loading conditions for timing light variables and IMU variables

	Loading Conditions (Mean ± SD)			Mean Difference (95% CI)			Effect Size (95% CI)		
Timing Light Variables	NL	WRs	WRf	NL - WRs	NL – WRf	WRs - WRf	NL - WRs	NL – WRf	WRs - WRf
Split 1 (s)	0.53 ± 0.03	0.56 ± 0.04	0.55 ± 0.38	-0.03* (-0.54 - -0.1)	-0.03* (-0.05 - -0.00)	0.01 (-0.2 – 0.03)	-0.79 (-1.45 - -0.25)	-0.67 (-1.26 - -0.16)	0.13 (-0.28 – 0.55)
Split 2 (s)	0.51 ± 0.04	0.53 ± 0.03	0.51 ± 0.03	-0.02† (-0.03 - -0.01)	-0.00 (-0.01 – 0.01)	0.02* (0.00 – 0.30)	-0.47 (-0.83 - - 0.17)	-0.06 (-0.27 – 0.14)	0.44 (-0.10 – 0.86)
Split 3 (s)	0.62 ± 0.07	0.62 ± 0.06	0.64 ± 0.09	0.00 (-0.04 – 0.04)	-0.02 (-0.07 – 0.03)	-0.02 (-0.7 – 0.02)	0.00 (-0.35 – 0.35)	-0.27 (-0.73 – 0.15)	-0.29 (-0.72 – 0.11)
Split 4 (s)	0.64 ± 0.04	0.64 ± 0.05	0.63 ± 0.03	-0.00 (-0.02 – 0.1)	0.01 (-0.03 – 0.05)	0.01 (-0.04 – 0.06)	-0.02 (-0.22 – 0.18)	0.22 (-0.43 – 0.90)	0.22 (-0.50 – 0.97)
Split 5 (s)	0.42 ± 0.03	0.43 ± 0.03	0.43 ± 0.03	-0.01 (-0.03 – 0.00)	-0.01 (-0.03 – 0.01)	0.00 (-0.03 – 0.03)	-0.46 (-0.93 - -0.06)	-0.33 (-0.85 – 0.16)	0.13 (-0.58 – 0.85)
Total Time (s)	2.74 ± 0.17	2.78 ± 0.18	2.78 ± 0.18	-0.05† (-0.81 - -0.13)	-0.04† (-0.07 - -0.01)	0.01 (-0.05 – 0.06)	-0.25 (-0.45 - -0.10)	-0.22 (-0.40 - -0.06)	0.03 (-0.09 – 0.16)
IMU Variables									
Max Speed (m/s)	5.29 ± 0.53	4.94 ± 0.55	4.99 ± 0.55	0.35† (0.19 – 0.51)	0.30† (0.13 – 0.48)	-0.05 (-0.25 – 0.15)	0.60 (-0.29 – 1.0)	0.51 (0.24 – 0.86)	-0.08 (-0.28 – 0.10)
Peak Acceleration (m/s^2)	4.13 ± 0.26	3.95 ± 0.30	4.00 ± 0.39	0.18† (0.13 – 0.23)	0.14 (-0.04 – 0.31)	-0.05 (-0.20 – 0.11)	0.60 (0.33 – 0.96)	0.37 (-0.00 – 0.80)	-0.12 (-0.43 – 0.17)
Peak Deceleration (m/s^2)	2.58 ± 0.27	2.39 ± 0.33	2.35 ± 0.22	0.19† (0.05 – 0.32)	0.22† (0.08 – 0.37)	0.04 (-0.14 – 0.21)	0.56 (0.21 – 1.0)	0.82 (0.33 – 1.45)	0.12 (-0.28 – 0.54)
Ground Contact Time (s)	0.34 ± 0.08	0.30 ± 0.05	0.32 ± 0.05	0.03 (-0.01 – 0.08)	0.02 (-0.02 – 0.06)	-0.01 (-0.04 – 0.01)	0.47 (-0.03 – 1.02)	0.30 (-0.12 – 0.77)	-0.23 (-0.61 – 0.12)

Key: * = p < 0.05, † = p < 0.01, CI = Confidence Intervals, NL= No load, SD = Standard deviation, WRf = Wearable resistance forearm, WRs = Wearable resistance shank

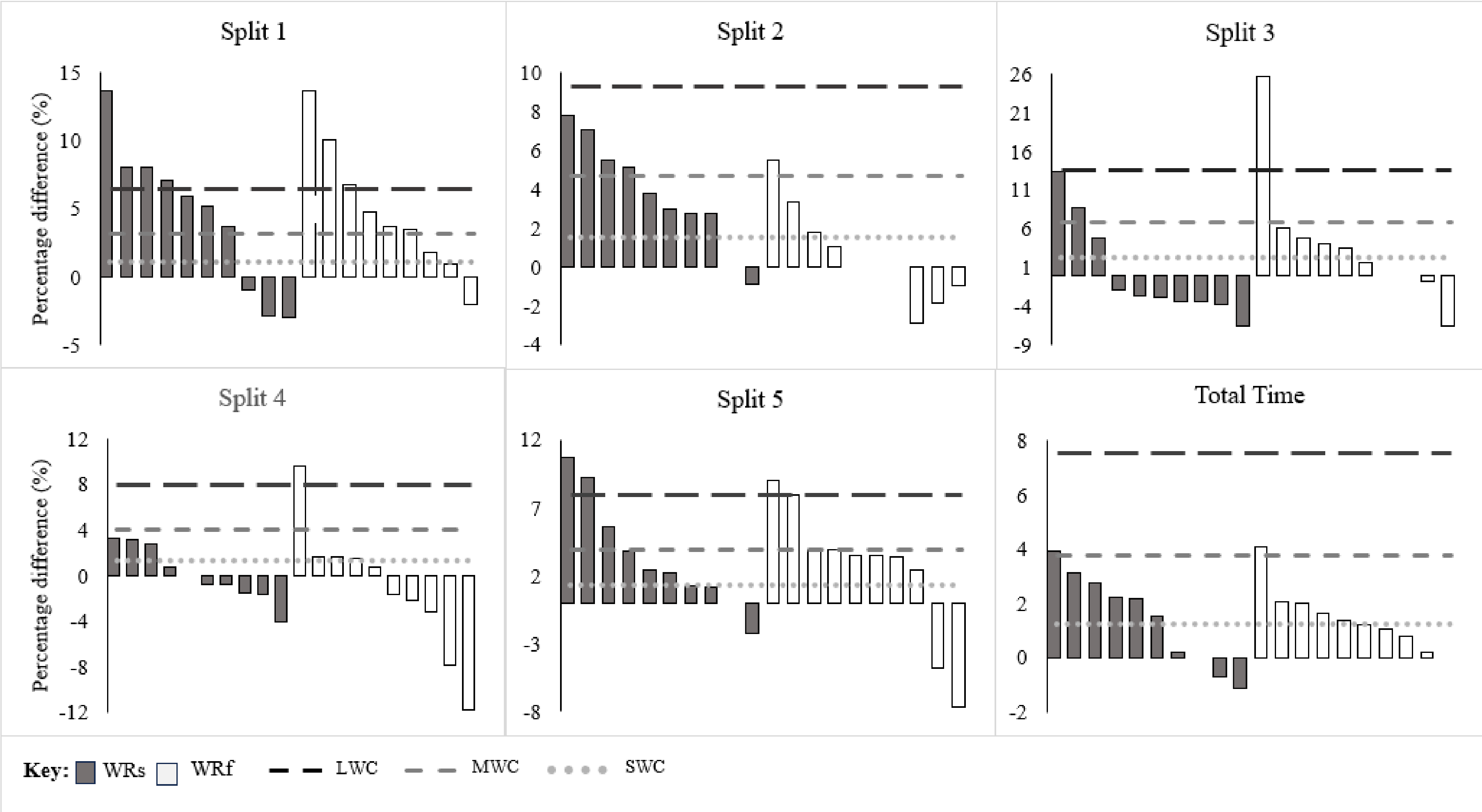

Figure 7.2: Individual time split responses to WR loading during the modified 5-0-5 COD test

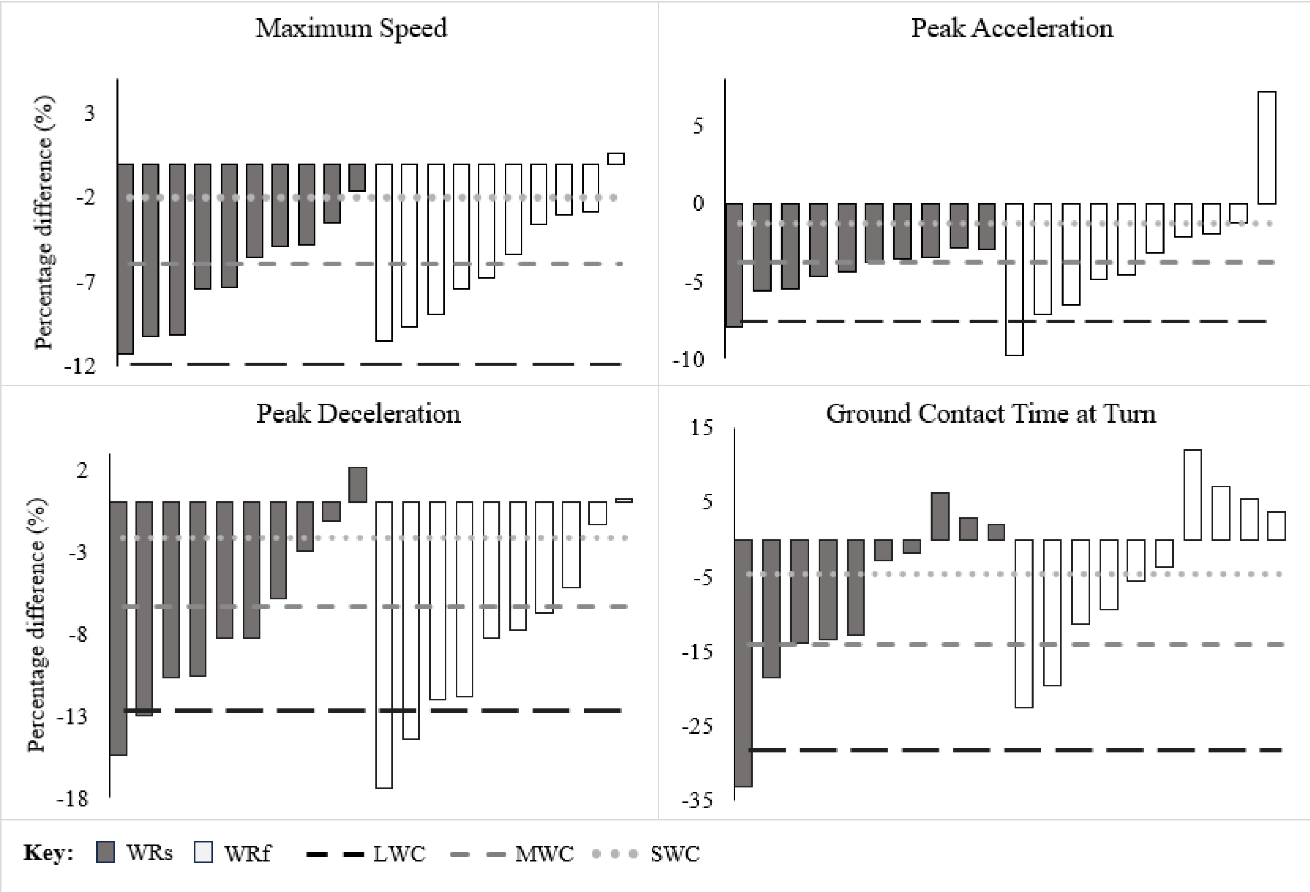

Figure 7.3: Individual responses to WR loading during the modified 5-0-5 COD test with IMU sensor

7.4 Discussion

The aim of this study was to determine the acute effects of forearm loading and shank loading compared to no load on 180° COD performance in netball athletes. The main findings were: 1) both WR loading conditions had a small to moderate significant effect on total time and the acceleration (split 1) time as compared to no load; 2) only shank loading had a small significant effect on the deceleration (split 2) time, compared to no load and forearm; 3) no significant differences were found during the COD phase (split 3); 4) the different WR loading had fairly similar effects, however peak acceleration was significantly affected by shank loading only as compared to no load; 5) no significant differences were observed between WR conditions on any of the IMU measures; and, 6) in terms of individual responses, 60% of athletes were above the SWC for total time, with similar results for acceleration (split 1) and reacceleration (split 5), while only shank loading appeared to affect the majority (80% above SWC) of athletes during deceleration (split 2), compared to forearm loading. This seminal study provides practitioners with knowledge pertaining to the acute effects of shank and arm loaded WR on COD performance. Given the importance of a training stimulus to have a slight acute effect in performance in order to elicit chronic adaptation if the stimulus is used consistently with the correct dosage and adequate recovery, the use of WR may provide a potential training method for inducing adaptation during specific phases of the 5-0-5 COD test (120).

Both forms of loading significantly increased total time during the modified 5-0-5 COD test compared to the no load condition. The authors expected there to be a small effect for both loading conditions, specifically during the linear phases (splits 1 and 4-5), as this would be where the athletes are moving the fastest, therefore creating the greatest rotational overload, however, trivial and small differences over the five splits led to small, yet significant increase in total time (ES = 0.22 – 0.25). During the initial acceleration phase of the modified 5-0-5 COD test, both shank and arm loading of 1% body mass had a significant effect on performance. To the authors knowledge, this is the first study to examine the acute effects of shank and forearm WR on the initial acceleration of a COD test, however previous researchers have explored the acute effects of different WR loading strategies on linear sprint acceleration (67, 128, 130, 134, 199, 227, 228). Simperingham and colleagues (199) found no significant acute effects on initial acceleration over 5 m using loads ranging from 3% to 5% body mass distributed across both the thigh and shank. The difference between these and the results of this study could be attributed to a combination of factors. Firstly, the physical determinants of rugby, differ from netball athletes in terms of the spatial-temporal demands associated with the dimensions of the court versus field (200, 220, 240). Secondly, the technologies used to quantify performance differed between studies, with Simperingham and colleagues (199), using radar technology and a non-motorised treadmill, whereas the current study used timing gates and IMU technology. Lastly, given the equation of rotational inertia (rotational inertia = mass x radius^2), the relatively greater distribution of mass in the current study i.e., all load placed below the knee, may influence performance due to the greater rotational inertia, thus a greater overload (52). With regards to arm loading, no significant acute effect during acceleration (0-10 m) were observed in the study of Uthoff et al (2020), using forearm loads of 1% BM. Conversely Macadam and colleagues (135), reported a small significant 2.1% difference in acceleration between forearm loaded (1% BM) and no load (ES = 0.46), which were similar to the results reported in this study (3.5%, ES = 0.67).

With regards to the deceleration performance, shank loading was found to significantly increase time during this phase (i.e., split 2) compared to both the no load and forearm loaded conditions. To the authors knowledge, no previous research has looked at a specific deceleration phase or metric during linear sprinting or COD whilst wearing shank or forearm loaded WR. It intuitively makes sense that shank loading had a larger overall effect on deceleration, as the load is placed distally from the axis of rotation (hip and knee joint) and directly overloads the specific joints and musculature such as the quadriceps and gastrocnemius used during deceleration (6, 97). Though the arm has a far greater load placed on it in proportion to segment mass, the distance from the axis of rotation is smaller than that of the shank, therefore it is possible that the shank loading has equal or greater rotational inertia compared to the forearm loading. The authors acknowledge that this is difficult to quantify, and all athletes will be different depending on anthropometrics. It is important to note that the population used in this research were above average height, given that they are elite netball athletes, therefore the distance from the axis of rotation may be greater than that of an average population. Additionally, from a practical standpoint, it proved difficult to attach load greater than 1% body mass to the athlete used in this research, due to a smaller surface area compared to the shank.

There were no significant differences reported for the COD phase (i.e., split 3), which was expected as during this COD phase, there is minimal rotational kinetic energy, as rotational velocity at the knee and hip is minimal, therefore limb loaded WR would have its least effects. There was a small effect (ES = -0.27) however, when comparing arm loading to no load. The authors hypothesised that forearm loading may have had a greater acute effect on the COD split, due to the importance of the arm movement during COD movements. When an athlete plants their foot to perform a COD, their inside arm pulls in a backward direction as the outside arm moves forward to assist rotation of the body (30). Whereas during this COD phase, there is limited rotational movement occurring at the hip, therefore it would be hypothesised that shank loading would have minimal effect on this phase.

No significant differences were reported for the reacceleration phases (i.e., split 4 and 5), however, there were significant differences reported for maximum speed measured with the IMU for both loaded conditions, compared to the non-loaded condition, but no differences were observed between loaded conditions. Maximum speed is likely to be occurring during the reacceleration phases, as this is when athletes have the largest distance to cover without the need to prepare for a COD, allowing them to reach their highest velocity. Additionally, only shank loading significantly affected peak acceleration as measured with the IMU, compared to both WR loading conditions affecting the acceleration timing split. This is most likely explained by the greater rotational inertia (I) of the shank loading given that the WR mass was located a greater distance (r) from the hip axis of rotation as compared to WR forearm placement i.e. $I = mr^2$ (67). Other potential reasons for the different acute effects could be attributed to technological differences such as: 1) whilst IMU is measuring at 416 Hz (416 samples per second) the timing lights only give information when the beams are broken e.g. ~0.5 s: 2) measurements occurring at different body parts i.e., timing lights are broken when the centre of mass passes through and breaks the beam, however the IMU is measuring what is happening directly at the foot: and, 3) the IMU peak acceleration is taken from one point (peak value), whereas the timing splits consider acceleration over a specified distance. Logically, it would appear that these two technologies are providing unique and independent information.

Though no significant differences were found between WR conditions on any of the measures, for timing light or IMU, except for the deceleration split (split 2), individual responses provide greater insight into the effects of each loading strategy. As shown in Figure 2, 60% of athletes were above the SWC for total time, with similar results for acceleration (split 1) and reacceleration (split 5), for both WR loading conditions. However, shank loading appeared to affect the majority (80% above SWC) of the athletes during the deceleration split (split 2), increasing split times as compared to forearm loading

(30% above SWC). Based on these graphical representations (Figure 2 and 3), it would appear the shank loading significantly affected more athletes, i.e., increasing split times and decreasing IMU variables (peak acceleration, peak deceleration and maximum speed) as compared to forearm loading.

In terms of previous studies, the authors have found limited research pertaining to the acute effects of WR during a COD task. One group of researchers investigated the acute effects of wearing 5% BM weighted vest, however this was during a 45° cutting movement in male soccer athletes, with no significant differences reported (122). Another research group investigated the acute effects of 1% body mass per leg attached to the shank and thigh during a 45° (cut) and 90° (turn) COD performance in male soccer athletes (186). They reported significant total time differences ($p < 0.05$) in both shank and thigh loaded conditions compared to unloaded, with the shank loaded protocol resulting in slower, yet not significant, total times compared to thigh loading. It is difficult to make comparisons across studies due to numerous reasons. Firstly, the degree of COD were different, with Rydså and van den Tillaar (185) reporting greater differences between interventions with the 90° turn compared to the 45° cut, which leads to the speculation that the larger the COD angle, the higher the overload of the WR. Secondly, the subjects used in the previous studies, have both used male soccer athletes, whereas this study has used female netball athletes. How different loading strategies effect male and female athletes is not yet documented, therefore it is difficult to make comparisons across sexes. Additionally, the physical determinants likely differ between field sports with large playing areas, versus court sports with relatively confined playing areas, therefore further research is necessary to elucidate acute adaptations to WR for different sporting codes.

7.4.1 Limitations

A limitation of this study was the sample size and population used, namely elite level netball athletes, meaning only a small number of participants were able to be recruited. However, we would assume that if the WR loading strategies caused an acute effect for elite netball athletes, a similar or greater effect would be observed for developing players, that are not as proficient at performing a 180° COD. Another limitation was that only one load (1% BM) was used in this study, and greater loading, such as 1.5 –

2% body mass on each limb, may induce larger effects on COD performance. However further research is needed to confirm this, as greater load would result in slower movements, and therefore less kinetic energy, potentially resulting in negligible effects. Additionally, the researchers were unable to fit more than 1% body mass loading to each arm on the female netball athletes, however further loading could be placed on the shank. Lastly, the authors did not capture videography alongside the other technologies used, therefore it is difficult to determine how different loading parameters affected technique during the 5-0-5 test.

7.5 Conclusions and Practical Applications

Using the modified 5-0-5 COD test with the phase splits and IMU measurements allows coaches and practitioners to be more granular with their programming. For example, if an athlete has a poor acceleration split, targeted acceleration programming should be used. In terms of WR, it appears that both shank and forearm loading can be used to induce acute changes to phases of COD performance. However, practitioners can use different loading strategies to train different phases of the modified 5-0-5 test. For example, if an athlete has poor decelerative ability, shank loading could be used due to shank loading having the greatest significant effect on mean deceleration measured via the timing split, and peak deceleration measured via the IMU. However, if an athlete is struggling with arm drive, or their COD phase, then forearm loading may be best. While both forms of load were observed to overload the initial acceleration phase, max speed and peak deceleration, shank loading also overloaded peak acceleration and deceleration performance prior to the COD phase. Therefore, if practitioners are limited to only being able to employ one loading protocol, shank loading would be recommended. This information provides practitioners with information regarding a new potential training stimulus that may elicit positive adaptations in COD performance if used over an extended period of time, however training interventions are needed to confirm this hypothesis. Additionally, further research is needed to determine the acute effects of WR loading on COD performance across different COD angles, with the use of video to determine the effects on technique. Additionally further research is needed to determine the different responses between male and female athletes.

CHAPTER 8 - EFFECTS OF WARMING UP WITH LOWER-BODY WEARABLE RESISTANCE ON CHANGE OF DIRECTION, LINEAR SPEED AND LEG POWER

This chapter comprises the following manuscript, which is under review at the *European Journal of Sport Science.*

Reference:

Ryan, C., Uthoff, A., McKenzie, C., & Cronin, J. (2024). Effects of warming up with lower-body wearable resistance on change of direction, linear speed, and leg power. *European Journal of Sport Science* (under 2nd review).

8.0 Prelude

In the previous chapter it was determined that both lower and upper limb WR had a significant acute effect on several kinematic variables during a modified 5-0-5 test. Though both loads provided a significant acute overload, the shank loaded WR affected more variables and therefore, shank loading was the preferred WR overload to use going forward. Given the acute findings of the previous Chapter, it was thought that WR may induce performance adaptation if used repeatedly during a training mesocycle. The load, frequency and duration of training needed with WR to induce COD adaptation is unknown. Furthermore, given the competing training demands of netball players, using WR as part of training rather than separate to it, may offer coaches a training solution to this problem. With these caveats in mind, the aim of this final experimental chapter was to determine the effects of shank loaded WR worn during a warm-up, on 5-0-5 COD sub-phase and total time performance, linear acceleration and single leg jump performance. If shown to enhance aspects of athletic performance, coaches could utilise this training tool during warm-ups and/or court training sessions to maintain or improve speed, power and COD performance.

8.1 Introduction

Netball is a team sport, most common among female athletes, which has one of the largest participation rates within the British Commonwealth (218). 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 (148, 150). 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 (102). Given that netball is a fast paced sport involving high velocity movements such as sprinting, jumping and change of direction (COD) (218, 229), 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 (33).

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 (129, 133, 227). 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 (136, 199, 237). Previous researchers have shown that lower limb WR loading affected ($p < 0.05$) acute COD performance (186), 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 and colleagues (184) 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 if repeated 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 (24), as well as enhance neuromuscular qualities of athletic performance. Previously Bustos and colleagues (33) investigated the effects of warming up with lower-body WR on athletic performance in male soccer players. Athletes performed a warmup with 200 - 600g 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 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 non-significant decreases in vertical jump performance ($p > 0.05$, ES = -0.17-0.21), however in terms of standing long jump performance, both WR and control group improved ($p \leq 0.018$; ES = 0.85 and 0.93, respectively; 86.7 and 62.5% > SWC, respectively). The researchers concluded that WR training elicited practically meaningful improvements in performance, even when it was implemented into a 15-20 minute 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 high school netball athletes (21, 148). Based on this previous research, it would appear that participating in a structured warm-up may elicit improvements in neuromuscular capabilities in young (13-16 years) 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 netball specific warm-up, as the current research has been implemented with male athletes (33, 49, 69). 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. Additionally, WR is a time-efficient method to induce training effects as it is implemented as part of practice rather than separate to it. Given this information, the aim of this study is to quantify the training effects of adding shank loaded WR loading to a netball specific warm-up in female netball athletes. It was hypothesised that sprinting, horizontal jumping and COD performance improvements would be greater in the WRT group as compared to the no load group.

8.2 Methods

8.2.1 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 one week pre- 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 (15.8 ± 0.9 yrs) 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 between groups was that the WRT group wore compression garments with 500 g – 1.2 kg (1 - 1.5% body mass) distributed on each shank during the on-court warm up two times per week.

8.2.2 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 versus control) and two time points (baseline and after 6-weeks). The analysis assumed a correlation of 0.7 among repeated measures, an effect size of 0.25, an alpha level of 0.05 and a 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 and Colleagues (147). Subjects were matched for COD ability and randomly allocated to either a WRT (n = 15, mean ± SD: age [yrs]: 15.8 ± 0.68; body mass [kgs]: 66.85 ± 10.92; height [cm]: 170.06 ± 4.10*)* or an unloaded CON group (n = 14, mean ± SD: age [yrs]: 16.14 ± 0.95; body mass [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, therefore were removed from the study. A total of 29 athletes completed the 6-week training program. Outside of the current warm up intervention, subjects were attending two court trainings, one gym session and one netball game per week. 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).

8.2.3 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 hours 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 3 trials for each performance test and were provided with approximately 2-minutes of rest between trials.

8.2.3.1 Linear Sprint Ability

A 15-m sprint was used to test linear sprint ability. VALD smart speed timing gates (VALD Performance, Queensland, Australia) were placed at 0-m (start), 5-m and 15-m. The start line was placed 0.5 m back from the first timing gate. Timing gates were set at a height of 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 at any one time (46).

8.2.3.2 Modified 5-0-5 Test

For the modified 5-0-5 COD test, an adapted set up was used, described by Ryan and colleagues (179). The modified set up with additional timing gates can be seen in Figure 8.1. 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.

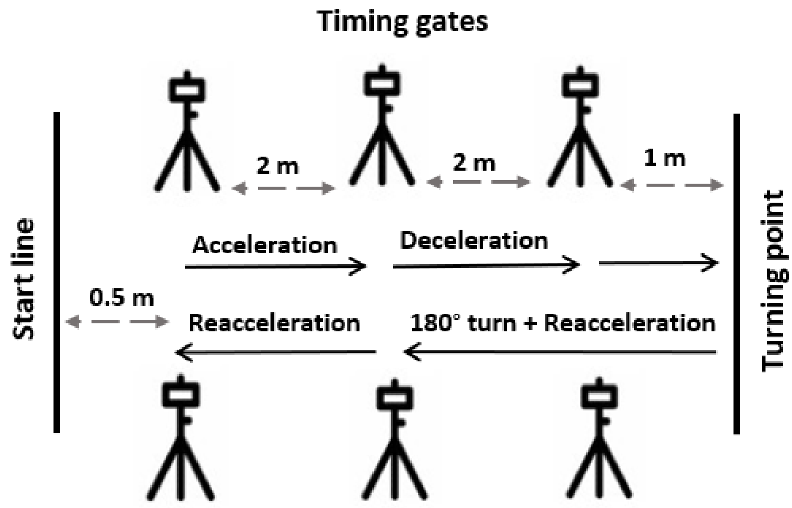

Figure 8.1: Modified 5-0-5 COD test set up with additional timing gates

8.2.3.4 SL Broad Jump

A single leg broad jump test was used as a proxy 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 minimize 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. The average of the three trials was used for analysis. This assessment has been reported to have acceptable reliability (CV = 2.7 – 3.1%, ICC = 0.95 – 0.98) (152).

8.2.3.5 SL Lateral Jump

A single leg lateral jump, as described by Hewit et al., (101) was used as a proxy 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 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 minimize 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. The average of the three trials was used for analysis. This assessment has been reported to have acceptable reliability (CV = 4.0 – 4.6%, ICC = 0.91 – 0.97) (152).

8.2.3.6 SL Vertical Jump

The SL vertical jump was performed on ForceDecks Dual force plates (VALD Performance, Queensland, Australia), which had a sampling frequency of 1000 Hz. 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 jump height, calculated via the impulse-momentum method, was averaged across the three trials. This assessment has been reported to have acceptable reliability (CV = 6.7 – 7.2%, ICC = 0.91 – 0.97) (152).

8.2.4 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 early in-season block. The only difference between groups was that the WRT group wore calf sleeves with 1 - 1.5% body mass during the 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 COD movements, with maximal effort jumps. The program has been provided as a supplementary Table (Appendix E). The WRT program consisted of progressively overloaded WR loads, ranging from 500 g – 1.2 kg (magnitude of load) placed evenly around the athlete’s calves (Figure 8.2) at varying lengths from proximal (near knee) to distal (near ankle). Training was conducted two times per week for 6 weeks, with a total of 12 sessions. The primary researcher delivered the warm-up with an assistant coach, resulting in a coach to player ratio 1:8. An overview of the loading scheme for the WRT group can be observed in Table 8.1.

Figure 8.2: Proximal shank loaded wearable resistance

8.2.5 Statistical analyses

All statistical analyses were performed using IBM SPSS statistical software package (version 27.0; IBM Corporation, New York, USA). Data was presented as mean ± standard deviation (SD). Normal distribution of the data was checked using Shapiro Wilk statistic. Homogeneity of variance was tested using the Levene's test. Preliminary analysis was done on no load condition between left and right legs, using a paired samples T-test. There were no significant differences between left and right leg data, therefore data was pooled for further analysis. 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 = 0.5-0.79, large effect = ≥ 0.8 (44). The smallest worthwhile individual change (SWC), moderate worthwhile change (MWC) and largest worthwhile change (LWC) was calculated on the pooled SD of the no load condition and converted to a percentage for each performance variable, where changes were deemed small (0.2 x SD), moderate (0.6 x SD), or large (1.2 x SD) (104).

Table 8.1: Periodised 6-week wearable resistance loading strategy for the WRT 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

8.3 Results

Within- and between-group results for pre- and post-training scores for WRT and CON groups are presented in Table 8.2 and 8.3. No significant differences were present between groups for COD total time at baseline. The individual responses for each group, relative to the worthwhile changes as a percentage, can be seen in Figures 8.3 - 8.5.

Table 8.2: 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 – 0.06)	-2.64	-0.71* (-0.13 – -1.26)	0.33 (-0.39 – 1.04)
	WRT	1.16 ± 0.05	1.11 ± 0.04	0.05 (0.04 – 0.07)	-4.41	-1.60* (-0.83 – -2.34)	
Linear Sprint (15 m split) (s)	CON	2.86 ± 0.14	2.74 ± 0.33	0.12 (-0.05 – 0.28)	-4.29	-0.40 (-0.13 – 0.89)	-0.31 (-1.01 – 0.41)
	WRT	2.84 ± 0.10	2.78 ± 0.10	0.06 (0.04 – 0.08)	-2.14	-1.55* (-0.79 – -2.28)	
5-0-5 Split 1 (s)	CON	0.55 ± 0.05	0.54 ± 0.04	0.01 (-0.01 – 0.04)	-1.83	-0.13 (-0.37 – 0.61)	0.47 (-0.26 – 1.18)
	WRT	0.56 ± 0.05	0.52 ± 0.04	0.04 (0.00 – 0.07)	-7.40	-0.60* (-0.06 – -1.12)	
5-0-5 Split 2 (s)	CON	0.49 ± 0.04	0.56 ± 0.04	-0.08 (-0.11 - -0.04)	13.3	1.05* (0.40 – 1.67)	-0.55 (-1.27 – 0.18)
	WRT	0.49 ± 0.05	0.59 ± 0.07	-0.11 (-0.14 - -0.08)	18.52	1.85* (1.01 – 2.67)	
5-0-5 Split 3 (s)	CON	1.38 ± 0.08	1.37 ± 0.13	0.02 (-0.03 – 0.07)	-0.73	-0.18 (-0.32 – 0.67)	0.74^{W} (0.00 – 1.47)
	WRT	1.40 ± 0.13	1.27 ± 0.13	0.12 (0.06 – 0.19)	-9.73	-1.02* (-0.40 – -1.62)	
5-0-5 Split 4 (s)	CON	0.47 ± 0.04	0.46 ± 0.03	0.01 (-0.01 – 0.03)	-2.15	0.20 (-0.30 – 0.70)	0.38 (-0.34 – 1.09)
	WRT	0.46 ± 0.02	0.45 ± 0.02	0.01 (-0.00 – 0.03)	-2.20	-0.38 (-0.12 – -0.87)	

5-0-5 Total Time (s)	CON	2.90 ± 0.14	2.92 ± 0.13	-0.02 (-0.08 – 0.04)	0.69	-0.18 (-0.68 – 0.32)	0.40 (-0.32 – 1.11)
	WRT	2.86 ± 0.08	2.86 ± 0.09	-0.01 (-0.04 – 0.03)	0.00	-0.07 (-0.56 – 0.43)	

Key: * = Significantly different (p <0.05) from pre-test, [W] = Significant between group difference in favour of WR group, CI = Confidence interval, ES = Effect size

Table 8.3: 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 – 0.02)	1.83	0.32 (-0.82 – 1.96)	-0.59 (-1.32 – 0.15)
	WRT	1.65 ± 0.16	1.71 ± 0.12	-0.06 (-0.11 - -0.01)	3.57	0.57* (0.04 – 1.08)	
Broad Jump (right leg) (m)	CON	1.59 ± 0.21	1.61 ± 0.17	-0.02 (-0.08 – 0.04)	1.25	0.14 (-0.64 – 0.36)	-0.48 (-1.19 – 0.25)
	WRT	1.64 ± 0.06	1.71 ± 0.10	-0.06 (-0.12 - -0.01)	4.18	0.67* (0.09 – 1.24)	
Lateral Jump (left leg) (m)	CON	1.44 ± 0.11	1.53 ± 0.13	-0.09 (-0.16 - -0.02)	6.06	0.73* (0.15 – 1.28)	-0.07 (-0.77 – 0.64)
	WRT	1.46 ± 0.16	1.56 ± 0.15	-0.09 (-0.15 - -0.03)	6.62	0.96* (0.36 – 1.55)	
Lateral Jump (right leg) (m)	CON	1.42 ± 0.07	1.50 ± 0.12	-0.08 (-0.14 - -0.02)	5.48	0.75* (0.15 – 1.32)	0.05 (-0.67 – 0.77)
	WRT	1.49 ± 0.15	1.56 ± 0.11	-0.74 (-0.14 - -0.02)	4.60	0.67* (0.12 – 1.20)	
Countermovement Jump (left leg) (cm)	CON	10.83 ± 3.83	11.79 ± 3.93	-0.96 (-2.36 – 0.45)	8.86	0.38 (0.15 – 0.91)	-0.02 (-0.76 – 0.72)
	WRT	13.54 ± 3.67	14.57 ± 3.08	-1.03 (-2.38 – 0.31)	7.61	0.40 (0.11 – 0.90)	
Countermovement Jump (right leg) (cm)	CON	11.07 ± 4.12	11.67 ± 3.64	-0.59 (-2.10 – 0.91)	5.42	-0.22 (-0.74 – 0.30)	0.25 (-0.48 – 0.97)
	WRT	13.67 ± 3.42	13.80 ± 3.92	-0.13 (-1.21 – 0.96)	0.95	-0.06 (-0.54 – 0.42)	

Key: * = Significantly different ($p<0.05$) from pre-test, CI = Confidence interval, ES = Effect size

8.3.1 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, 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%).

8.3.2 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 ($p < 0.05$) split 3 (180° turn) time (9.73%, ES = 1.02), and a significant difference between groups was 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.

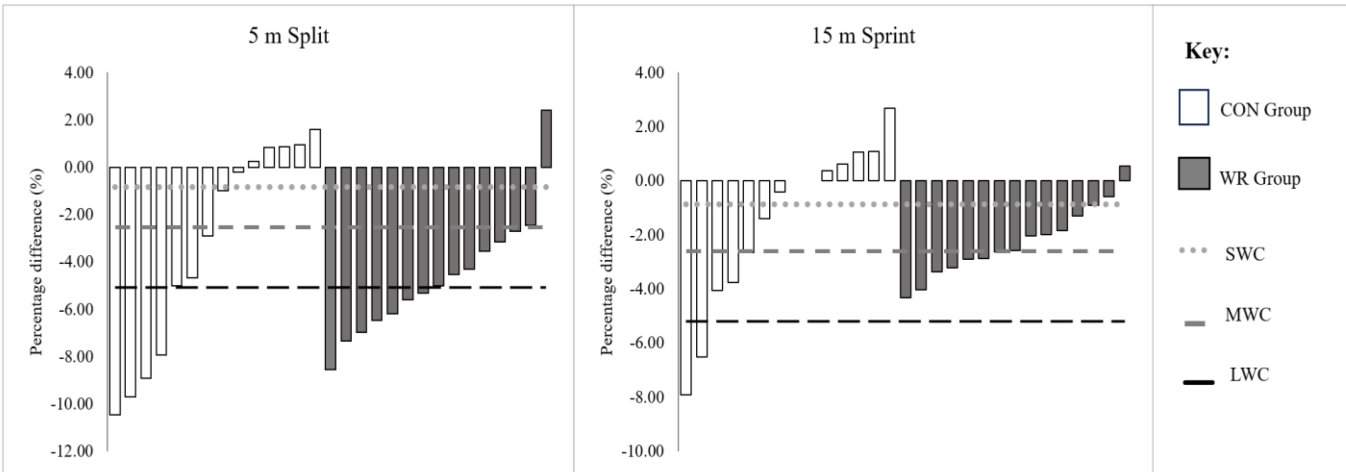

Figure 8.3: Individual responses for sprint times

8.3.3 Jumping

The results for pre and post jump performance can be observed in Table 8.3. The WRT group increased ($p < 0.05$) broad 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, and 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 broad 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 ($p > 0.05$) observed between the groups. Once again, the WRT group had the 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 height for either leg. The WRT group had slightly higher individual response rates for CMJ height on both left and right legs (60.00% and 33.33% respectively) compared to the CON group (42.86% and 21.43%, respectively). There were no significant differences between groups.

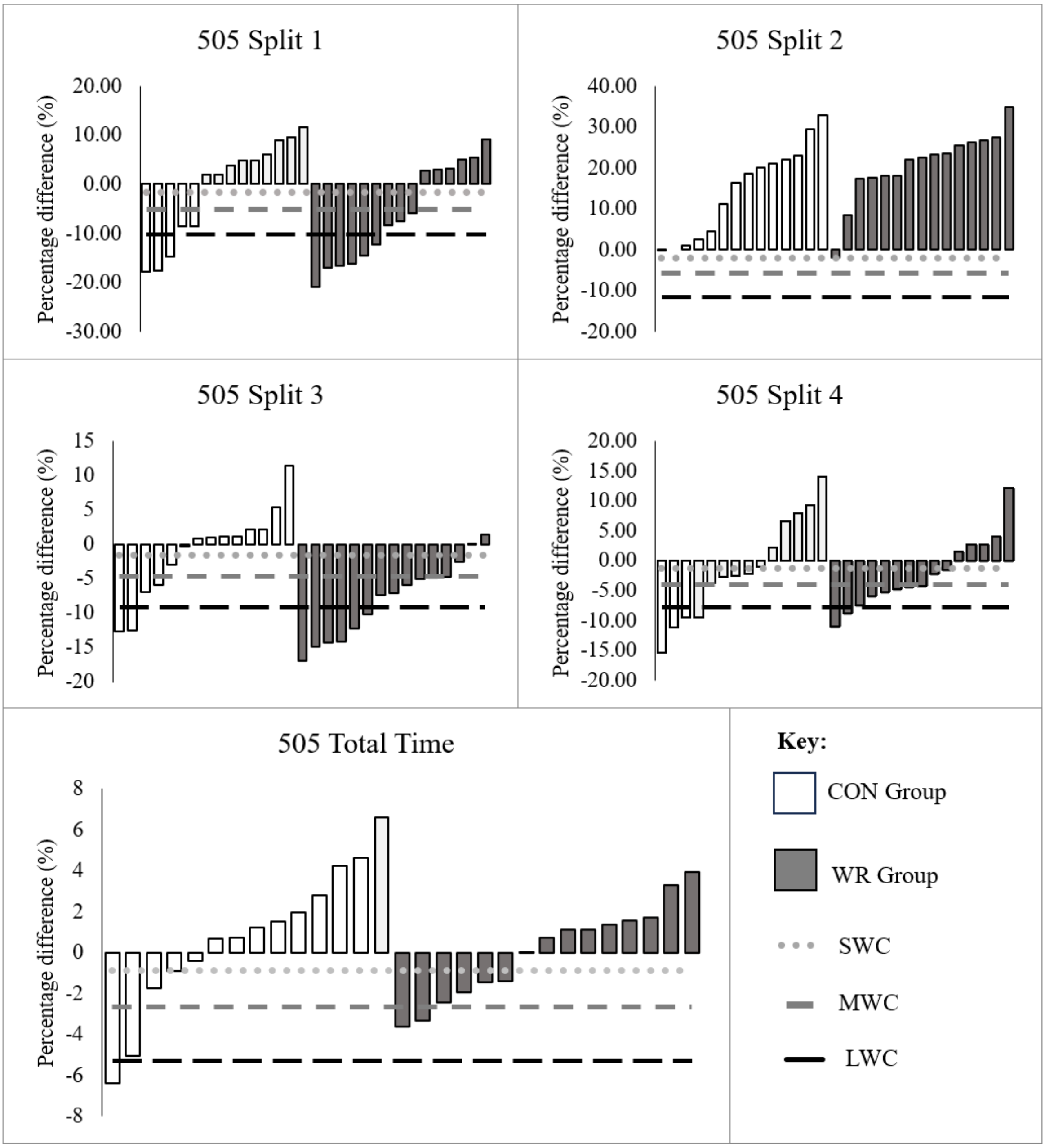

Figure 8.4: Individual responses for change of direction times

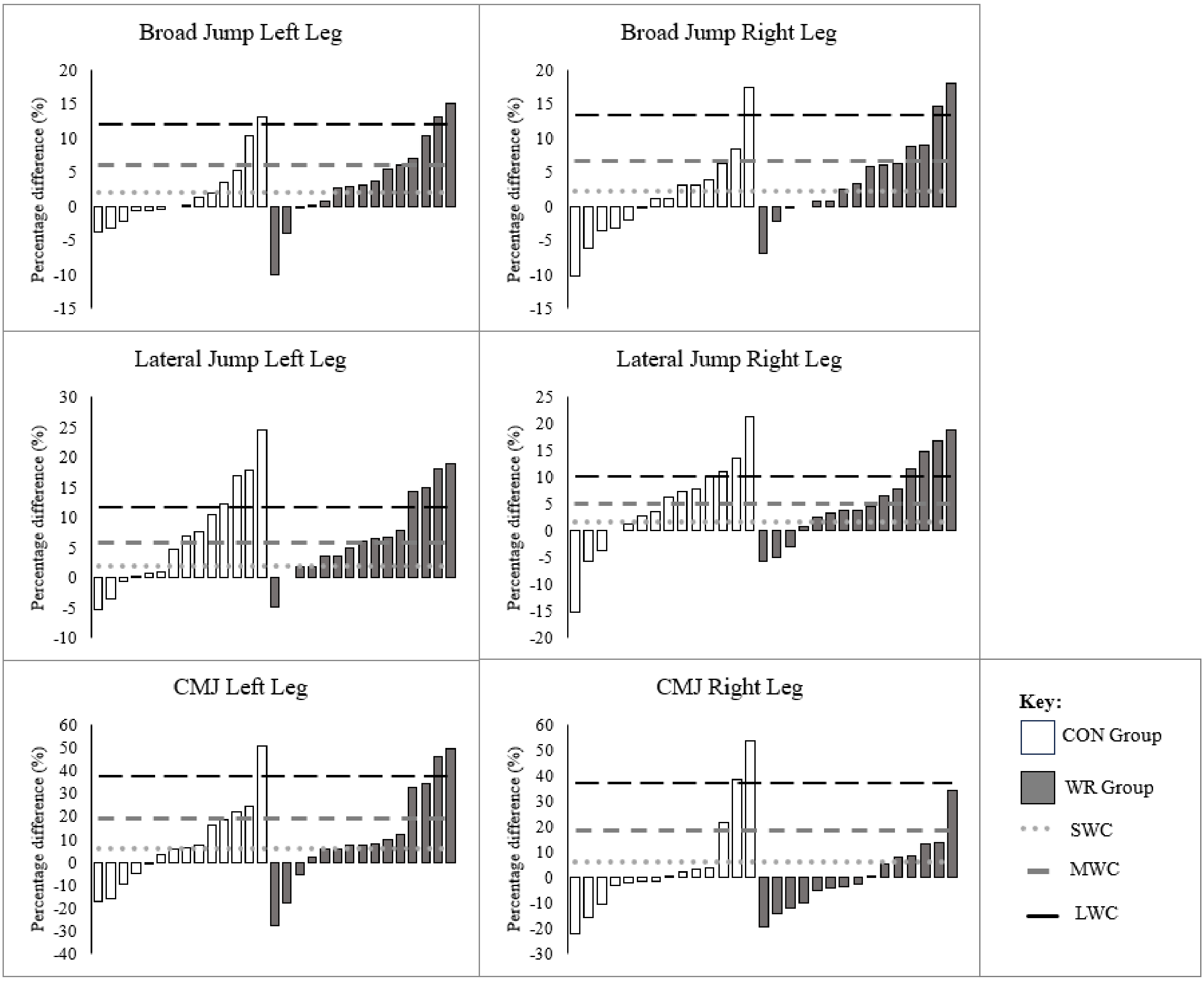

Figure 8.5: Individual responses for single leg jumps

8.4 Discussion

This was the first study to investigate the training effects of WR shank loading on female netball athletes. It was hypothesised that performance changes in sprinting and 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: 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 were 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 broad jump performance.

Though both groups significantly decreased their 5-m split time, the WRT group training effect size (ES = -1.60), was twice that of the CON (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% (> LWC), 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 decreases ($p < 0.05$, -2.14%; ES = -1.55) in 15 m linear sprint times, compared to performing the warm-up program unloaded ($p < 0.05$, -4.29%, ES = -0.40). 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 and colleagues (33), who determined the effect of warming up with shank-loaded WR in male soccer players over an 8-week period. The authors reported significant ($p < 0.05$) improvements in 10 m 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, which results in greater muscular work due to the angular kinetic energy i.e. 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 was the first study to determine the effectiveness of WR training on COD performance. Previously Ryan and colleagues (184) suggested that training with shank 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 ($p < 0.05$) in time during the COD turn and reacceleration out of the turn (-9.73%, split 3). Furthermore, there was a significant difference with moderate effects between groups in favour of the WRT for this split (split 3). Interestingly, 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 did have 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 (55), 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 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 likely resulting in changes in deceleration strategy.

In terms of jump performance, the WRT group significantly increased their single leg broad jump performance (right leg: 4.18%, ES = 0.67, left leg: 3.57%, ES = -0.57), which was once again, similar to the results reported by Bustos et al., (33) (6.25%, ES = 0.77). These results weren't surprising, given the nature of the training and principles of overload and specificity i.e., 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 broad 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 (183). 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 and colleagues (33), 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 non-significance, is likely due to the individual responses seen in Figure 8.5, 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 observed 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 – 1.5% body mass each leg. However, it proved difficult to add any more than 1.5% body mass to each leg 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, and playing level. Furthermore, it is likely the dose-response relationship needs exploring, i.e., three vs two sessions per week. Lastly, only one COD test was used (modified 5-0-5 i.e., 180°), different adaptations may have been observed in other COD tests using different entry velocities or COD angles.

8.5 Conclusion

Wearing shank-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 response ratios. 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., 2-3 times per week), different exercises and warm-up protocols, and in a range of different sports and levels.

CHAPTER 9 - SUMMARY, FUTURE RESEARCH DIRECTIONS AND PRACTICAL APPLICATIONS

9.1 Summary

The ability to change direction is considered a key determinant of successful participation in many field and court sports (196). One of the most common COD movements is the 180° turn (99), which can be measured through the traditional and modified 5-0-5 COD tests, these tests providing the focus of this thesis. Previous researchers have focused on non-specific training methods such as resistance training (16, 115, 156) and plyometrics (8, 23, 168), for enhancing COD performance, however it has been speculated that specific COD training may yield superior improvements in COD performance (51). Despite this contention, there is limited research in this area (20, 23, 53), with many of the trainings being primarily linear sprint focused.

The use of WR has become increasingly popular in recent years. WR involves the use of micro-loads attached to compression garments, overloading movement in a more sport or activity specific manner. Limb loading WR provides a rotational overload and increases the mechanical work associated with a movement. This training tool was hypothesised to provide a sport specific overload to COD training, which in turn would potentially improve COD performance over an extended period of time.

The aim of this PhD was to answer the overarching question, “Can wearable resistance improve change of direction performance in female netball athletes?” A series of reviews and experimental studies were used to answer this overarching question. Below is the aim for each chapter and a summary of the notable findings.

The aim of Chapter 2 was to determine what normative and reliability data currently exists for the traditional and modified 5-0-5 COD test. It was found that traditional 5-0-5 COD ability of male athletes (n = 300) was better understood, compared to females (n = 62), with male athletes on average being

6.03% faster than females. Elite males were reported to be 7.78% faster than sub-elite and novice males, while sub-elite females on average were 3.30% faster than novice females. In terms of the modified 5-0-5 test, only male results were found, with cricket athletes being the fastest (2.70 seconds). Given these findings, it was evident there was a lack of research with female athletes, especially at the elite level. In terms of test reliability, both the traditional and modified 5-0-5 tests have been reported reliable, however all studies were performed with novice or sub-elite athletes. The most common piece of equipment used to measure COD performance were timing gates (dual beam), however the authors only provided a total time for the assessment, which provided limited diagnostic value, given that COD is a complex task that requires athletes to optimise acceleration, deceleration, turning and reacceleration.

In Chapter 3 the current and most utilised COD model by Sheppard and Young (196), was discussed, and a new model proposed by the authors was presented, focusing on specific leg strength qualities (concentric, eccentric, isometric and reactive strength) and their relationship to 5-0-5 COD performance. Based on the current literature it was evident that high levels of eccentric strength were required to rapidly decelerate the body prior to the turn, with eccentric strength having the strongest correlation to 5-0-5 COD performance (207). Concentric strength was hypothesised to be related to the acceleration/first step quickness and reacceleration phases, while isometric strength was hypothesised to be related to the COD phase, however this is likely technique dependant. The authors also proposed a new way to advance the diagnostic value of a traditional and modified 5-0-5 test by splitting it into distinctive phases (acceleration, deceleration, 180° turn and reacceleration), by adding two extra timing gates. This advanced and novel method may be of high utility to sport scientists and strength and conditioning coaches in terms of providing more granular information about the various phases of the 5-0-5. Additionally, it was briefly discussed that the inclusion of more advanced technology such as inertial sensors, could also be implemented during testing to provide more kinematic information.

The focus of Chapters 4 and 5 was to determine the reliability of two novel diagnostic protocols used during the modified 5-0-5 COD test. The additional timing gates proposed in Chapter 3, to isolate the sub-phases, were used in Chapter 4. Ten elite female netball athletes volunteered to participate in this research to determine the reliability of this novel method. It was found that all phases and total time had acceptable reliability (CV < 10%, ICC = 0.57 – 0.97) and no systematic bias was observed across the three sessions. The inter-relationship between the sub-phases was also explored and it was found that only one sub-phase explained more than 50% of the shared variance (deceleration and acceleration) between phases, indicating that these sub-phases are measuring relatively independent qualities. The 180° turn had the greatest shared variance with total time (R^2 = 88.4%). Advancing the diagnostics of the 5-0-5 by incorporating IMU technology was the focus of Chapter 5. In this chapter firstly, the reliability of various IMU variables during a modified 5-0-5 COD test were quantified and secondly, the inter-relationship between the different IMU and timing light split variables were determined. Absolute consistency was acceptable (CV < 10%) for all variables, except for ground contact time. All ICCs were greater than 0.80, with the exception of peak deceleration on the left leg turn and there appeared to be no systematic change across the three testing sessions. In terms of the IMU metrics, the biggest predictor for total time measured with timing gates was peak acceleration (R^2 = 0.95)

In Chapter 6 a more practical approach was undertaken, using the data that was collected with the novel diagnostic set-up (additional timing gates). This chapter provided coaches with insight into the time spent in each sub-phase, factors that may affect COD performance and how to present sub-phase data in a team sport environment to identify individual athlete strengths and weaknesses. Of particular interest in this Chapter was to: 1) understand what proportion of the test was actually spent changing direction; 2) determine whether anthropometry (weight and height) and positional differences influenced sub-phase performance; and, 3) whether a sub-phase analysis could provide better diagnostic information to guide individualisation of programming. From the analysis it was found the majority of the time was spent during the 180° turn and reacceleration 1 sub-phases (~23%). There were significant performance differences with very large effects between heavier and lighter athletes for total time, in three out of the five sub-phases (deceleration, 180° turn and reacceleration 2). Additionally, the athletes with the best overall total time weren’t necessarily the best at all the sub-phases. The use of a sub-ranking analysis within a team or athletes of the same sport, may provide greater diagnostic information to guide better programming and targeted COD training.

The acute effects of different WR loading strategies (shank and forearm) on modified 5-0-5 COD performance were determined in Chapter 7. It was found that both forearm and shank loaded WR had small to moderate significant effects on total time (ES = -0.22 and -0.25 respectively) and the acceleration split (ES = -0.67 and -0.79 respectively) compared to no load, however, only shank loading had a small significant negative effect on the deceleration split (ES = -0.47). No significant differences were found during the COD phase for either loaded condition. In terms of the IMU variables, the WR loading had similar effects, however peak acceleration was significantly decreased by shank loading only, as compared to no load (ES = 0.60). With regards to individual responses, 60% of the athletes were above the SWC for total time for both conditions, with similar results for acceleration split and reacceleration split, while only shank loading appeared to affect the majority (80% above SWC) of athletes during the deceleration split compared to forearm loading. It was concluded that both shank and forearm loading could be used to induce acute changes to phases of COD performance, however, if practitioners are limited to one WR garment, shank loading would be recommended due to the additional acute overload on peak acceleration and deceleration performance.

The chronic effects of lower limb WR worn during a warm-up, on 5-0-5 COD performance were investigated in Chapter 8. It was found that both the WRT group and CON group decreased (ES = -1.60 and -0.71; $p < 0.05$, respectively) their 5 m linear sprint split time, however, only the WRT group significantly decreased their 15 m sprint time (ES = -1.55). Whilst there were no significant changes in total time for the modified 5-0-5 test, the WRT group significantly decreased their acceleration (ES = -0.60) and COD (ES = -1.02) split times. Both groups significantly increased their deceleration split time (CON ES = 1.05, WR ES = 1.85) during the modified 5-0-5 test. In terms of single leg jump performance, both groups increased their single leg lateral jump (CON ES = 0.73 – 0.75, WR ES = 0.67 – 0.96), while only the WRT group significantly increased their broad jump performance (ES = 0.57-

0.67). The authors concluded that wearing shank-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 the turn phases of a modified 5-0-5 test, and horizontal jump ability in female netball athletes. Though there were no improvements in 5-0-5 total time, WR did enhance certain aspects of the test i.e., higher entry velocities and COD phases, which were positive adaptations. In terms of why there was no decrease in 5-0-5 total time it may be that there was not enough specific deceleration training, and therefore the athletes were not prepared for the higher entry speeds into the COD, therefore had to brake earlier thus cancelling out the adaptations.

9.2 Practical Applications

Strength and conditioning practitioners are constantly looking for safe and effective methods to enhance their athletes COD, sprinting and jumping ability but may be limited by time or resources. This thesis was intended to provide practitioners a novel method for firstly measuring and assessing COD performance, and secondly, a time efficient way for specifically training COD performance. Resulting from the findings in this thesis, the following applications/recommendations are offered from each Chapter:

Chapter 2

1. The normative data tables provided are valuable information for coaches and practitioners and allow comparisons of their athletes, to other athletes of the same sport, sex, and level of performance. This allows coaches to set benchmarks for their athletes, especially for those wanting to reach an elite level.
2. Practitioners can be confident that timing gates, specifically dual beam timing gates, are reliable for measuring traditional and modified 5-0-5 COD total time performance.
3. The 5-0-5 COD test has been reported to have good discriminant validity; therefore, coaches can use it to differentiate between athletes of different levels and may be used to assist in talent identification and athlete monitoring.

Chapter 3

1. A new perspective on understanding and assessing COD performance was provided, highlighting the limitations of a single total time, when it is evident that it consists of different phases (acceleration, deceleration, turn and reacceleration).
2. The muscle qualities most associated with 5-0-5 performance were identified, to better inform coaches programming. For example, it was found that high levels of eccentric strength have the strongest correlation to 5-0-5 performance, likely due to the rapid deceleration of the body prior to the turn.
3. An advanced diagnostic protocol for coaches to integrate into their assessments was proposed, by adding two additional timing gates into the normal 5-0-5 testing, thereby creating sub-phases. Though this approach was used with the 5-0-5 test, this method could be employed in various other assessments, such as the Y-agility or 90° cut test.
4. By segmenting 5-0-5 total time into component times, coaches and practitioners can be more targeted with feedback and programming to improve COD and therefore sporting performance.

Chapter 4

1. In Chapter 4, it was identified that an advanced timing light set up can be used to reliably assess phase-specific performance in a 5-0-5 COD test. This therefore allows applied practitioners to be more granular with their assessment and programming.
2. A key finding of this chapter is that elite netball athletes displayed similar between session split times and total times, suggesting little variability in movement strategies during this test.

Chapter 5

1. It appears that the use of an IMU in-sole can advance the diagnostic value of the modified 5-0-5 test, by providing additional information on peak acceleration, deceleration and speed achieved during these assessments.

2. Because of the seamless incorporation of the technology, i.e., athletes just place them in their shoes as insoles, it is an easy tool to integrate into both assessments and trainings. Additionally, it allows comparisons from assessments to trainings and to games. You can compare the demand of the assessment you choose, to the demands of the trainings, and then to the demands of the game. For example, if your athlete isn't reaching the same magnitude and frequency of accelerations and decelerations in their training, as compared to games, coaches may question whether they are effectively preparing their athlete for the demands of the game. This deeper insight provided by this technology can advance the way coaches assess and program their athletes. For example, a coach may implement "top-ups" at the end of a practice to compensate in any acceleration/deceleration deficits.
3. This tool can also assist coaches and practitioners with identifying areas of strengths and weaknesses for their athlete's. For example, if an athlete has poor peak deceleration performance, it is likely that more horizontal eccentric-decelerative training is needed. If they have a slow ground contact time at the 180° turn, they likely need to improve their reactive strength.
4. Though the measurements were reliable, their validity, specifically during a 5-0-5 test is unknown, so coaches should be aware of this when deciding whether to incorporate this tool into their assessments.

Chapter 6

1. By taking a sub-phase approach, it provides the practitioner with higher level diagnostics, which can inform programming in a more granular manner. This approach allows principles of individualisation and specificity to be more easily achieved. For example, two players of the same position may have identical total time values, however they are both achieved differently. One may have excellent braking and decelerative capabilities but poor turn performance, while the other has excellent acceleration but poor deceleration. Both athletes have the same total

time score, however, to improve their total time performance, you would train these athletes differently.

2. Body mass does affect a player's ability to perform a 180° turn, with heavier players producing significantly slower times during three of the sub-phases and total time. Therefore, coaches can focus on improving accelerative ability, which is a large aspect of COD performance, by either increasing force capability (in particular horizontal accelerative and decelerative force capability) and/or decreasing fat mass i.e. acceleration = force/mass. Similarly, in terms of the impulse-momentum relationship (f x t = m x v), the same impulse will produce a greater movement velocity if mass is reduced.
3. Coaches may find the use of rank order tables for presenting performance times for a sub-phase approach during a modified 5-0-5 COD test useful for providing insight into an athlete's different strengths and weaknesses. This method of data presentation enables coaches to develop more targeted programming to improve COD performance.

Chapter 7

1. Both forearm and shank loading can be used to induce acute overload, however practitioners can use different loading strategies to train different phases of the modified 5-0-5, based on strengths and weaknesses identified using the advanced diagnostic protocol outlined in previous Chapters. For example, if an athlete is identified to have poor deceleration (split 2 and peak deceleration) shank loading would seem the best loading option compared to forearm loading.
2. If practitioners are only limited to one loading choice, shank loading is recommended, given its overall larger effect on 5-0-5 performance, compared to forearm loading.
3. This information provides practitioners with new insight into a potential training stimulus that may elicit positive adaptations in COD performance if used for an extended period of time.

Chapter 8

1. Wearing shank loaded WR improved linear sprint ability when worn during on-court warm-ups. Therefore, if coaches are looking to increase their athletes speed, without dedicated training sessions, it is recommended to use shank loaded WR.
2. Though no improvements were reported for total time during the modified 5-0-5 test, there were significant improvements for acceleration, 180° turn and reacceleration phases. Therefore, if an athlete has poor acceleration and turning ability, lower limb WR would be recommended to incorporate into warm-ups and court trainings to enhance this area of performance.
3. Based on the findings of improvements in horizontal jump performance, coaches can use shank loaded WR to improve horizontal force capability.
4. Shank loaded WR would be recommended to coaches working in environments where time is limited. You can incorporate this training tool into your athletes' warm-up to induce positive performance results, rather than having a dedicated sprint and agility training session.

9.3 Limitations

It is important for the reader to be cognisant of the following limitations when interpreting the results of this thesis.

1. It is acknowledged that the systematic review could have included more conditions regarding the methodological description, for example, starting distance from the first gate, surface type, timing light height etc., however, the subsequent analysis would be cumbersome and the data in each condition would be limited, therefore provided limited value.
2. Chapters 4-7 used elite level netball athletes; therefore, the results should only be generalised to that specific population.
3. Though it was hypothesised and proposed that certain muscle actions (i.e., concentric, eccentric, isometric and reactive strength) are associated with each timing split, this is speculative, and further research is needed to determine whether this is true.

4. The position of the timing gates was decided on practical simplicity and comparing time over equal distances. The timing splits were a proxy of where each phase may occur, though this will be slightly different for all athletes, however it offered an easy and simple way to provide additional information on COD performance in a team sport environment.
5. In terms of the training study, the authors could not secure the same elite cohort for the research, as it is hard to get permission from coaches, physiotherapists etc., to work with elite athletes with a tool or protocol that has not yet proven to be safe or effective, therefore top level high-school athletes were used for the training study.
6. The sample size for the reliability and acute studies were small, due to the fact that the participants were of an elite level and the only team in this province, meant only a small number of participants were able to be recruited. In terms of the reliability aspect, this was primarily a descriptive study and therefore sample size was of less importance. With regards to the correlational analysis, even with small sample size strong and significant correlations were determined, which with a larger more heterogeneous sample, the correlations would likely have been even stronger. It is acknowledged that larger sample sizes would strengthen the reliability and precision of the correlation, enhancing the validity of any inferences made.
7. The author did not capture video footage alongside other technologies, therefore it is difficult to determine how different loading parameters affected technique and biomechanics during a 5-0-5 test, however, it should be noted that video footage was not permitted when working with the elite level athletes.
8. The control groups in the training study were active controls. All athletes were encouraged to only participate in their netball trainings where they all performed the same program, however their activity was not quantified and may have influenced the response or lack thereof observed in each group. However, due to the active nature of young athletes, active controls are commonly used when researching training effects in youth (151, 187, 225, 234).
9. The training study duration was limited to 6-weeks (8 -week including pre and post testing) and only two sessions a week due to term time, school, and class constraints. Additionally, the

training program was part of the athletes' warm-up and therefore was only approximately 20 minutes in duration. Long-term training studies with higher volume (frequency, loading, exercises) and longer duration training sessions may provide a more comprehensive understanding of the longitudinal effects of lower limb WR training. However, the training study reflected how firstly, the programme could be implemented within the length of a typical school term during pre-season and secondly, how it can be integrated into a warm-up if time is limited. Though a longer training period would have been ideal, the researcher only had 8-weeks with these athletes prior to the mid-year school holidays, where athletes would not be training. The length of this study is similar to other sprint, agility and plyometric training (59, 68, 154, 236, 242).

10. It is acknowledged that more in depth information on participants reproductive profiles, especially within the training study could have been collected to determine influence on outcomes. However, it is assumed that the randomisation process would have mitigated this influence to some extent.
11. The studies in this thesis are de-limited to female netball athletes. Generalising the findings of this research to males, or different sports should be performed with caution. However, this thesis offers a snapshot of female netball athlete responses to different WR loading parameters and the long-term effects of lower-limb WR on different athletic performance measures.
12. Similar to many previous studies on specific COD and sprint training, the author only measured performance directly pre-training and post-training (33, 59, 225). Therefore, it is unknown whether there is a supercompensatory effect, or the rate of detraining, following training cessation.
13. In the acute study, the author had a total of five timing splits (acceleration, deceleration, COD, reacceleration 1 and reacceleration 2), however unfortunately during the training study, the researcher only had access to a different set of timing lights, which didn't allow the measurement of all five splits. Therefore, in the training study, the COD and reacceleration 1

phase were combined, however this was consistent for pre- and post-testing for the training study.

14. Though it was shown that IMU technology could advance the diagnostics of the modified 5-0-5 COD test, it was not feasible to incorporate this into the training study, given the testing durations allowed by the coaches. Additionally, some athletes who require insoles in their training shoes, found that these footpods were uncomfortable and therefore may have affected their performance in some manner. Finally, at this point in time the technology had not been validated for COD performance and due to the elite nature of the cohort, filming of players was not allowed.
15. In terms of further progressive overload (>1.5% BM each limb), increasing load would be difficult given the surface area of the shank of these female athletes. To progress the loading further, it may be best to also load the thigh, however further research is needed into the effect of thigh + shank loading on COD performance.

9.4 Future Research Directions

The aim of this thesis was to assist strength and conditioning practitioners with understanding whether WR training could be a tool for improving athletic performance, with a specific focus on the 5-0-5 COD test. Considering the findings, and limitations of this thesis, the following recommendations can be made for future research:

1. It has been suggested that concentric, eccentric, isometric and reactive strength are associated with different phases of the modified 5-0-5 test (183), however this theory can be applied to all types of directional changes. Researchers should investigate the predictive ability of these strength qualities for phases of COD. Also, the influence of the different starts to the acceleration and reacceleration phases i.e., static anterior-posterior start versus dynamic lateral propulsive start needs further investigation.
2. Given the training effects, it is evident that lower limb WR results in beneficial performance responses, however, knowledge into the underlying determinants responsible for promoting the

observed adaptations should be further investigated. Acute studies could use a series of in-ground force platforms to help understand how WR overloads different kinetic variables, along with video to better understand how kinematic variables are affected, specifically during COD tasks.

3. This thesis only focused on 180° COD performance, however as alluded to in previous chapters, different adaptations may be seen with different degrees of directional change. Given the inverse relationship between angle and entry velocity during a COD task, it is likely that WR may have a greater impact on smaller COD angles e.g., 45-90°, where entry velocities can remain high, and less braking is required in order to complete the directional change (55).
4. Empirical training studies commonly include pre-training and post-training performance measurements, however only quantifying performance at these two points may not provide the full picture of the adaptive responses. Some training modalities need time for adaptations to manifest due to fatigue and supercompensation. Additionally, with the addition of more testing occasions, detraining affects after training cessation could be determined. Therefore, in order to improve exercise prescription and maximise training responses to WR, the author suggests that future researchers should attempt to quantify periods of supercompensation and detraining.
5. This research only incorporated WR into a modified netball warm-up, greater adaptation may have occurred if it was worn during dedicated COD and sprint training sessions. Researchers should examine the chronic effects of training with WR for longer durations i.e., 30 – 40-minute dedicated COD sessions, across a variety of frequencies (2-4 times per week).
6. With the advent of new technologies such as IMU’s and motorised resistance, there is scope to establish the validity, reliability and sensitivity of these emergent devices for capturing COD performance. These devices may in turn provide advanced diagnostics to better inform exercise prescription to optimise the training of the sub-phases.

9.5 Conclusion

This thesis provided original academic research into firstly, how to advance diagnostics of an existing COD test (5-0-5 test) and secondly how limb loaded WR can be implemented in a team sport with minimal disruption to training, and its application for improving athletic performance in female netball athletes. Strength and conditioning coaches can utilise the information presented in this thesis to better understand the importance of measuring COD beyond total time, thereby informing training and programming decisions, and appreciating why WR should be considered for athletic training. While future research is needed to further elucidate the effectiveness of WR as a method to promote athleticism, the results of this thesis are promising, as it provides a novel stimulus for athletes which they can wear during their regular team warm-up and drills.

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APPENDIX A: ETHICAL APPROVAL FOR CHAPTERS 4-7

TE WĀNANGA ARONUI O TĀMAKI MAKAU RAU

Auckland University of Technology Ethics Committee (AUTEC)

Auckland University of Technology
D-88, Private Bag 92006, Auckland 1142, NZ
T: +64 9 921 9999 ext. 8316
E: ethics@aut.ac.nz
www.aut.ac.nz/researchethics

14 April 2021

Aaron Uthoff
Faculty of Health and Environmental Sciences

Dear Aaron

Re Ethics Application: **20/402 Effects of different WR loading strategies on change of direction performance in elite female netball athletes, using a modified 505 test with an advanced diagnostic protocol**

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 14 April 2024.

Non-Standard Conditions of Approval

1. Please ensure that data and Consent Forms will be stored separately in the SPRINZ database

Non-standard conditions must be completed before commencing your study. Non-standard conditions do not need to be submitted to or reviewed by AUTEC before commencing your study.

Standard Conditions of Approval

1. The research is to be undertaken in accordance with the Auckland University of Technology Code of Conduct for Research and as approved by AUTEC in this application.
2. A progress report is due annually on the anniversary of the approval date, using the EA2 form.
3. A final report is due at the expiration of the approval period, or, upon completion of project, using the EA3 form.
4. Any amendments to the project must be approved by AUTEC prior to being implemented. Amendments can be requested using the EA2 form.
5. Any serious or unexpected adverse events must be reported to AUTEC Secretariat as a matter of priority.
6. Any unforeseen events that might affect continued ethical acceptability of the project should also be reported to the AUTEC Secretariat as a matter of priority.
7. It is your responsibility to ensure that the spelling and grammar of documents being provided to participants or external organisations is of a high standard and that all the dates on the documents are updated.

AUTEC grants ethical approval only. You are responsible for obtaining management approval for access for your research from any institution or organisation at which your research is being conducted and you need to meet all ethical, legal, public health, and locality obligations or requirements for the jurisdictions in which the research is being undertaken.

Please quote the application number and title on all future correspondence related to this project.

For any enquiries please contact ethics@aut.ac.nz. The forms mentioned above are available online through http://www.aut.ac.nz/research/researchethics

(This is a computer-generated letter for which no signature is required)

The AUTEC Secretariat
Auckland University of Technology Ethics Committee

Cc: Chloe.ryan@xtra.co.nz; John Cronin; Chloe-McKenzie

APPENDX B: ETHICAL APPROVAL FOR CHAPTER 8

TE WĀNANGA ARONUI
O TĀMAKI MAKAU RAU

Auckland University of Technology Ethics Committee (AUTEC)

25 May 2023

Aaron Uthoff
Faculty of Health and Environmental Sciences

Dear Aaron

Re Ethics Application: **23/25 The chronic effects of upper body and lower body wearable resistance training on 5-0-5 change of direction performance in female netball athletes.**

Thank you for your responses to AUTEC's conditions.

Your ethics application has been approved for three years until 25 May 2026.

Standard Conditions of Approval

1. The research is to be undertaken in accordance with the Auckland University of Technology Code of Conduct for Research and as approved by AUTEC.
2. All public facing documents must have the AUTEC approval number and be of a high standard of spelling and grammar. Dates on the Information Sheet(s) and Consent Form(s) must be consistent.
3. Any amendments to the project must be approved by AUTEC prior to being implemented.
4. A progress report is due annually on the anniversary of the approval date.
5. A final report is due at the expiration of the approval period, or, upon completion of project.
6. Any serious or adverse events must be reported to AUTEC, this includes unforeseen issues that might affect continued ethical acceptability of the project.
7. AUTEC grants ethical approval only. You are responsible for obtaining management permission for access from any institution or organisation at which your research is being conducted and you need to meet all ethical, legal, public health, and locality obligations or requirements for the jurisdictions in which the research is being undertaken.

The application number and title need to be referenced on all correspondence related to this project.

All forms are available online http://www.aut.ac.nz/research/researchethics

For any enquiries, please contact ethics@aut.ac.nz
(This is a computer-generated letter for which no signature is required)

The AUTEC Secretariat
Auckland University of Technology Ethics Committee

Cc: Chloe.ryan@xtra.co.nz; Chloe-McKenzie; john.cronin@aut.ac.nz

APPENDX C: CHAPTER 2 SUPPLEMENTARY MATERIAL

Table 2.5: Studies that have used the traditional 5-0-5 change of direction test.

Author	Sport	N=	Sex	Age (years)	Level	Performance (s)	Measurement device
Alvurdu et al., 2019 (5)	Soccer	26	Male	9.4 ± 0.5	Sub-elite	3.0 ± 0.3	Timing gates
Atkins et al., 2020 (10)	Basketball	30	Male	22.5 ± 4.1	Novice	2.63 ± 0.22	Timing gates
Bell et al., 2016 (22)	Soccer	16	Male	25 ± 4.0	Sub-elite	2.34 ± 0.11	Timing gates
Bridgeman et al., 2020 (29)	Rugby Union	8	Male	18.7 ± 1.0	Sub-elite	2.48 ± 0.11	Timing gates
Chaalali et al., 2016 (38)	Soccer	32	Male	14.5 ± 0.9	Elite	2.42 ± 0.15	Timing gates
Davies et al., 2009 (48)	Netball and Basketball	11	Male [4] Female [7]	26.3 ± 5.1 19.7 ± 0.5	Sub-elite	2.54 ± 0.17 2.63 ± 0.12	Timing gates
Gabbett et al., 2008 (79)	Rugby league	42	Male	23.6 ± 5.3	Novice & Sub-elite	1st Grade (n=12): 2.34 ± 0.20 2nd Grade (n=30): 2.39 ± 0.15	Timing Gates
Houghton et al., 2013 (105)	Cricket	19	Male	21 ± 4.0	Novice	2.26 ± 0.06	NR
Jones et al., 2009 (110)	Various sports	38	Male [33] Female [5]	21.5 ± 3.0	Novice	2.34 ± 0.12	Timing gates
Kalkhoven & Watsford, 2018 (113)	Soccer	22	Male	21.9 ± 1.5	Sub-elite	NR	Timing gates
Kulakowski et al., 2020 (119)	Lacrosse	17	Female	18 ± 0.7	Sub-elite	L: 2.5 ± 0.20 R: 2.6 ± 0.20	Timing gates
Madueno et al., 2018 (139)	Basketball	8	Male and Female	19.9 ± 1.5	Sub-elite	NR	Timing gates

Maluleke, 2019 (140)	Soccer	13	Male	19.3 ± 1.8	Novice	L: 2.46 ± 0.23 R: 2.46 ± 0.14	Timing gates
Maraga et al., 2018 (142)	Tennis	6	Male	12.8 ± 1.2	Sub-elite	R: 2.48 ± 0.12 L: 2.50 ± 0.13	Timing gates
Mulazimoglu et al., 2017 (160)	Soccer	12	Male	23.3 ± 1.83	Novice	2.54 ± 0.19	Timing gates
Nimphius et al., 2010 (167)	Softball	10	Female	18.1 ± 1.6	Sub-elite	NR	Timing gates
Pruyn et al., 2014 (173)	Netball	18	Female	23.6 ± 2.7	Novice	2.72 ± 0.18	Timing gates
Sarvestan et al., 2020 (188)	Range of sports	24	Male	21.67±2.29	Novice	NR	Infrared motion capture
Sayers, 2015 (192)	Rugby league	15	Male	24.6 ± 4.7	Novice	2.60 ± 0.16	Timing gates
Scanlan et al., 2018 (194)	Basketball	8	Male [6] Female [2]	19.9±1.5	Sub-elite	NR	Timing gates
Singa et al., 2020 (201)	Rugby Union	14	Male	22.64 ± 1.865	Novice	2.520 ± 0.23	NR
Spiteri et al., 2019 (206)	Basketball	45	Female	Collegiate (15): 20.3± 2.7 WNBL (15): 24.2 ± 2.5 WNBA (15): 26.2 ± 4.9	Sub-elite and Elite	R: 4.43 ± 0.12 L: 4.44 ± 0.12 R: 4.58 ± 0.17 L: 4.59 ± 0.14 R: 4.27 ± 0.16 L: 4.27 ± 0.25	Timing gates
Teo et al., 2016 (215)	Recreationally active	26	Male	24.2 ± 1.11	Novice	2.43 ± 0.12	Timing gates
Thomas et al., 2016 (219)	Cricket	18	Male	17.1 ± 0.70	Sub-elite	R: 2.37 ± 0.10 L: 2.40 ± 0.12	Timing gates
Torreblanca-Martinez et al., 2020 (222)	Soccer	19	Male	18.42 ± 0.69	Elite	R: 2.28 ± 0.6 L: 2.29 ± 0.6	COD timer app

Tramel et al., 2019 (223)	Volleyball	10	Female	19.1 ± 1.20	Sub-elite	R: 5.25 ± 0.22 L: 5.21 ± 0.21	NR
Venter et al., 2017 (230)	Netball	20	Female	19.95 ± 1.76	Sub-elite	2.69 ± 0.11	Timing gates

Key: R= Right leg, L= Left leg, NR= Not reported,

Table 2.6: Studies that have used the modified 5-0-5 change of direction test.

Study	**Sport**	**N=**	**Sex**	**Age (years)**	**Level**	**Performance (s)**	**Measurement device**
Fernandez- Fernandez et al., 2020 (65)	Tennis	29	Male	15.09 ± 1.16	Sub-elite	DOM: 2.77 ± 0.08 NDOM: 2.87 ± 0.08	Timing gates
Fernandez- Fernandez et al., 2018 (66)	Tennis	16	Male	12.9 ± 0.4	Novice	2.75 ± 0.16	Timing gates
Gabbett et al., 2008 (77)	Rugby league	42	Male	23.6 ± 5.3	Novice & Sub-elite	1st Grade: 2.66 ± 0.14 2nd Grade: 2.71 ± 0.17	Timing Gates
Gallo-Salazar et al., 2017 (80)	Tennis	12	Not reported	14.4 ± 0.9	Sub-elite	DOM: 2.90 ± 0.17 NDOM: 2.94 ± 0.10	Timing gates
Hernández-Davó, 2020 (96)	Handball Soccer Tennis	19 12 19	Male	16.9 ± 0.4 17.1 ± 0.7 16.8 ± 0.8	Novice	NR	Timing gates
Lopez-Samanes et al., 2021 (126)	Tennis	11	Male	20.6 ± 3.5	Elite	2.86 ± 0.14	Timing gates
Moya-Ramon et al., 2020 (158)	Tennis	20	Male	16.5 ± 0.3	Novice	DOM: 2.95 ± 0.07 NDOM: 3.02 ± 0.07	Timing gates
Murphy et al., 2015 (161)	Tennis	30	Males and females	17 ± 1.3	Sub-elite	R: 2.68 ±0.13 L: 2.68 ±0.13	Timing gates
Thomas et al., 2015 (216)	Soccer Rugby league	14	Male	21 ± 2.4	Novice	NR	Timing gates

Thomas et al., 2016 (219)	Cricket	18	Male	17.1 ± 0.7	Sub-elite	R: 2.70 ± 0.15 L: 2.70 ± 0.11	Timing gates

Key: R= Right leg, L= Left leg, NR= Not reported, DOM= Dominant leg, NDOM= Non-dominant leg

APPENDIX D: CHAPTER 5 SUPPLEMENTARY MATERIAL

Supplementary Table 5.3: Correlation matrix between IMU variables and timing light variables for left and right leg turns during a modified 5-0-5 COD test.

	Max Speed L	Peak Decel L	Peak Accel L	GCT L	Max Speed R	Peak Decel R	Peak Accel R	GCT R	L 505 Split 1	L 505 Split 2	L 505 Split 3	L 505 Split 4	L 505 Split 5	L 505 Total	R 505 Split 1	R 505 Split 2	R 505 Split 3	R 505 Split 4	R 505 Split 5	R 505 Total
Max Speed L	1																			
Peak Decel L	-.71*	1																		
Peak Accel L	.82**	-.48	1																	
GCT Left	-.01	-.25	-.16	1																
Max Speed R	.98***	-.72*	.81**	-.03	1															
Peak Decel R	-.48	.79**	-.44	-.17	-.52	1														
Peak Accel R	.84**	-.55	.97**	-.02	.86**	-.56	1													
GCT R	-.21	-.13	-.26	.81**	-.13	-.30	-.04	1												
L 505 Split 1	-.50	.32	-.56	.27	-.59	.43	-.67*	-.06	1											
L 505 Split 2	-.59	.28	-.89**	.35	-.60	.34	-.86**	.27	.71*	1										
L 505 Split 3	-.76*	.63	-.67*	-.11	-.79**	.65*	-.78**	-.12	.73*	.60	1									
L 505 Split 4	-.78**	.44	-.79**	.05	-.71*	.33	-.71*	.33	.23	.48	.42	1								

High correlation (r = 0.7 to 1.0)

Moderate correlation (r = 0.5 to 0.7)

Low correlation (r = 0 to 0.5)

L 505 Split 5	-.65*	.59	-.77**	.25	-.63	.54	-.77**	.22	.60	.85**	.54	.47	1							
L 505 Total	-.86**	.62	-.91**	.07	-.89**	.63	-.96**	.10	.70*	.82**	.90**	.63*	.73*							
R 505 Split 1	-.51	.33	-0.53	-.06	-.60	.53	-.68*	-.34	.89**	.53	.75*	.35	.39	.68	1					
R 505 Split 2	-.54	.34	-.79**	.28	-.62	.41	-.83**	.05	.73*	.89**	.48	.38	.82**	.72*	.59	1				
R 505 Split 3	-.90**	.55	-.78**	-.05	-.92**	.35	-.83**	.12	.53	.62	.84**	.57	.52	.89	.53	.53	1			
R 505 Split 4	-.37	.49	-.40	-.71*	-.36	.49	-.46	-.51	.12	.12	.46	.51	.11	.41	.43	.09	.33	1		
R 505 Split 5	-.54	.47	-.69*	.55	-.57	.30	-.61	.50	.49	.76*	.29	.40	.83**	.56	.18	.79**	.42	-.13	1	
R 505 Total	-.89**	.63	-.90**	-.01	-.93**	.57	-.97**	.00	.74*	.78**	.88**	.65*	.70*	.97**	.75*	.75*	.91***	.46	.56	1

* = Correlation is significant at the 0.05 level, ** = Correlation is significant at the 0.01 level

APPENDIX E: CHAPTER 8 SUPPLEMENTARY MATERIAL

Supplementary Table 8.4: Intervention Exercises – Modified NZ Netball Smart Warm-up

Exercise	Distance	Reps	Rest (seconds)	Notes
Running	15 m	3	0	Run to the centre of the court and back
High knees + Butt Kicks	15 m	2	30	High knees to halfway, Butt kicks back to base
Side Shuffle	15 m	2	30	Side shuffle as fast as possible to halfway and back
Walking Lunge + Twist	15 m	1	30	Walking lunge + twist to halfway and walk back
Leg Swings	N/A	10	30	Grab on to your partner and complete 10 swings each leg.
Hip Swivels	N/A	5 each side	30	Standing in position and moving feet quickly 90° and back, working on dissociation between hips and shoulders
Quick forwards and backwards	15 m	2	60	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. Jog back.
Bound and stick	15 m	2	30	Prop from one foot to another and then “stick” final landing for 2 seconds in a stable body position.
Vertical Jump 180° land	N/A	5	30	Jump up with hands on hips, twist 180°s in the air and land on two feet.
Shuffle to run	15 m	2	30	Shuffle to the first transverse line and back, turn 90° and sprint to halfway.
Crossover Run	15 m	2	30	Crossover to transverse line and back turn 90° and sprint to halfway.
Sprints	15 m	3	60	Linear sprint to the last cone (middle of the court), increasing the intensity each set. Start at 80% then go to 90% and 100%.
Fast feet (5 seconds) to 90° turn to sprint + Stop (progress to lunge stop, reactive stops and transition stops)	15m	2 each way	2 min	Alternating left and right 90° turns

Please note* Warm-up was performed on a standard netball court (30.5 x 15.25 metres)

Appendix E Continued: Participant Information Sheet

TE WĀNANGA ARONUI O TĀMAKI MAKAU RAU

Participant Information Sheet

Date Information Sheet Produced:

January 2023.

Project Title

The chronic effects of training with wearable resistance on modified 5-0-5 change of direction performance in female netball athetes.

An Invitation

My name is Chloe Ryan and I am a PhD student at Auckland University of Technology (AUT). I am currently conducting a study into the long-term effects of external loading to the forearm and calf using a new sports technology called Exogen™ exoskeleton (*see photos below*) on modified 5-0-5 change of direction (COD) performance. Your participation in this study would be greatly valued, but is entirely voluntary. If you choose to participate in this study, you may withdraw at any time, prior to the completion of the data collection. In order to participate in this study, you must be a female between the ages of 16-18 years, currently playing high school level netball, and not have any current injuries or a medical condition that can affect your ability to perform the testing and training required.

Information gained from this research will be presented in a way so that your name and personal details remain confidential (i.e., de-identified). The results of the study will be provided in the form of journal or thesis publications and/or conference presentations.

Your consent to participate in this research will be indicated by your signing and dating the accompanying consent form. Signing the consent form indicates that you have read and understood this information sheet, freely give your consent to participate, and that there has been no coercion or inducement to participate.

What is the purpose of this research?

The purpose of this research is to understand whether wearing the Exogen™ arm sleeves or calf sleeves improves jumping, sprinting, and change of direction performance. Exogen™ exoskeletons include arm and calf sleeves which small (approximately 19 cm long) loads of 50 – 300g can be attached with Velcro. This research will measure the effects of training with wearable resistance attached to the forearm or calf on typical sporting movements and the phases of the modified 5-0-5 COD test. Sprint and COD assessments will be measured using timing light technology, while jump performance will be measured using force plate technology and basic measuring equipment. The findings of this research will be used for the thesis of the primary researcher, Chloe, conference presentation(s) and academic publication(s).

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

You were identified for this project because you are healthy, injury-free, competitively active female netball player aged 16-18 years old, and are not a past or present client of the primary researcher. You meet these criteria so we would like to invite you to participate.

How do I agree to participate in this research?

If you agree to participate in this study, please complete the accompanying consent form. This form will be collected in person prior to testing. Your participation in this research is voluntary (it is your choice) and whether or not you choose to participate will neither advantage nor disadvantage you. You are able to withdraw from the study at any time. If you choose to withdraw from the study, then you will be offered the choice between having any data that is identifiable as belonging to you removed or allowing it to continue to be used. However, once the findings have been produced, removal of your data may not be possible.

What will happen in this research?

As part of this study, you will provide current measures of age, height, and weight.

If you choose to participate in the chronic training study, you will be required to complete four one hour testing sessions, as well as 16 training sessions. These training sessions will be incorporated into your regular training. The testing sessions will take place at your regular training location.

You will complete a standardised warm-up prior to all testing and you will have a recovery period of at least two minutes before each maximal effort test. Following the standardised warm-up you will complete selected tests from the following list:

Chronic effects of forearm and shank loaded WR on modified 5-0-5 change of direction performance

The pre-intervention testing session will provide you, the participant, with a briefing the participants on the study procedures and your characteristics (i.e., age, height, BM, and level of competition) will be collected. You will perform a standardized warmup consisting of submaximal jumps, progressive sprint and COD drills interspersed with dynamic lower-body stretching. See the table below for what tests will be completed during each of the four testing sessions.

Table 1. What will be measured, and how

Test	Metric	Equipment
Modified 5-0-5 COD tets	Sub-phase and total time of the modified 5-0-5 test	3x timing gates
Sprint test	20 m sprint (with 5 m split)	2x timing gates
Single leg vertical jump	Jump height, peak force, rate of force development	VALD force plates
Single leg horizontal jump	Jump distance	1x measuring tape
Single leg lateral jump	Jump distance	1x measuring tape

Upon completion of the pre-intervention testing session, yet prior to the start of the intervention, you will be matched based on your change of direction ability, and randomly assigned to one of three groups: a control group, a forearm loaded group, and a calf loaded group. The control group will do the normal warm up and training without any additional load, while the forearm loaded and calf loaded groups will do the normal warm up and training with additional weights on their arms and legs, respectively. See Table 2 for the periodised training plan for each experimental group.

Table 2. Periodised 8-week WR loading strategy for WR groups

Week	Load placement (WRf and WRs groups)	Load (WRf and WRs groups)
1	Proximal	0.5% BM
2	Distal	0.5% BM
3	Proximal	1% BM

4	**Mid-intervention testing**	N/A
5	Proximal	1% BM
6	Proximal - Distal	1% BM
7	Distal	1% BM
8	Distal and Deload	1% BM

The training intervention will take place during the 8 weeks between pre- and post-intervention testing. All groups will continue with their typical training schedule, which will be accounted for. The control group, Wearable Resistance Forearm, and Wearable Resistance Calf groups will perform their normal standardised NZ Netball Smart warm-up, with a few modifications (see table below). However, only those participating in the experimental groups will perform the warm-ups with WR on the forearm (WRf) or shank (WRc).

Table 3. Intervention Exercises – Modified NZ Netball Smart Warm-up

Exercise	Distance	Reps	Rest (seconds)	Notes
Linear running	15 m	2	30	Run to the centre of the court and back
Running hip out	15 m	2	30	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.
Butt kicks + skipping	15 m	2		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.
Running circling partner	15 m	2	30	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.
Running shoulder contact	15 m	2	30	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.
Quick forwards and backwards	15 m	2	60	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.
Hip swivels	N/A	5 each leg	30	Standing in position and moving feet quickly 90° and back, working on dissociation between hips and shoulders
Walking lunges	N/A	5 each side	30	Standing with feet hip-width apart and hands on hips. Lunge forward and bend your hips and knees to 90-degrees. Keep hips, knees and foot in a straight line.
Vertical Jump 180-degree land	N/A	5	30	Jump up with hands on hips, twist 180-degrees in the air and land on two feet.
Prop, prop and stick	15 m	2	30	Prop from one foot to another and then "stick" final landing for 2 seconds in a stable body position.
Running – plant and cut	15 m	2	30	Run to first cone, plant, and cut off on an angle towards opposite cone. Continue length of 15 metre and back
Sprints	15 m	3	60	Linear sprint to the last cone (middle of the court), increasing the intensity each set. Start at 80% then go to 90% and 100%.
Fast feet to 90° turn to sprint	15m	2 each way	2 min	Alternating left and right 90° turns

AUT

TE WĀNANGA ARONUI O TĀMAKI MAKAU RAU

What are the discomforts and risks?

There should be no significant discomforts or risks associated with this testing beyond those experienced during normal sport testing and training. You will likely experience some shortness of breath and perhaps some lower body muscular soreness in the 48 hours after each testing session.

You will be individually fitted and given the same wearable resistance garments on each occasion. Forearm and calf (shank) sleeves can be worn either directly on your skin, or over your own tight-fitting garments. The suits will be washed between each use.

How will these discomforts and risks be alleviated?

You will be requested to not complete any high-intensity training in the 48 hours prior to each testing session and to present to each testing session well hydrated and having not eaten in the 90 minutes prior to the start of testing. You will perform a comprehensive warm-up and cool-down before and after each testing session. Full recovery of at least two minutes will be ensured before each maximal effort test.

What are the benefits?

The research findings will inform and improve the effectiveness of athletic training procedures particularly in the areas of speed, power, and change of direction training. As a participant you can receive a report of the research outcomes and your individual results at the completion of the study. These results can be used to individualise your on-going strength and conditioning program decisions. Additionally, a summary of your results can be made available to your team coach, manager, or doctor if you agree to this on the consent form.

What compensation is available for injury or negligence?

There is no compensation for this research, and you are undertaking voluntarily.

For research conducted in New Zealand; 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.

All efforts have been made to ensure a safe testing environment and methodology. There are appropriate first aid equipment / facilities and trained staff to manage any adverse events during testing.

How will my privacy be protected?

- We will take a number of measures to protect your privacy as much as possible and to ensure your personal details remain confidential.
- 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 (2020).
- All reference to participants will be by code number, participant information will be reported as de-identified, aggregated data. 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 obtained from the participants.
- De-identified test results (i.e. without your associated name and personal details) may be stored indefinitely in the encrypted SPRINZ research database.
- The findings of this project will be published in scientific journals, at a conference presentation(s) and in a doctoral thesis, but at no stage will you be identifiable. The results will be presented as averages and not individual responses. Your identifiable test results will only be made available to yourself and your sports coach, manager, or doctor (if you agree to this option on the consent form).

What are the costs of participating in this research?

Participating in this research project will not cost you apart from your time, which we greatly thank you for. The total time commitment will be one familiarisation session (this will take place at your usual training location), a minimum of 16 one hour training sessions over a 8 week period during which you will be required to wear the Exogen exoskeleton with a specified amount of added weight attached, however this training sessions will be incorporated into your regular netball training. Additionally, you will be required to attend four one hour testing sessions over a 10 week period.

What opportunity do I have to consider this invitation?

- Please take the necessary time (up to 2 weeks) you need to consider the invitation to participate in this research.
- It is reiterated that your participation in this research is completely voluntary, and you are between 16 and 18 years of age.
- If you require further information about the research please feel free to contact Dr Aaron Uthoff (details are at the bottom of this information sheet).
- You may withdraw from the study at any time without there being any adverse consequences of any kind.
- You may ask for a copy of your results at any time and you have the option of requesting a report of the research outcomes at the completion of the study.

Will I receive feedback on the results of this research?

We will provide a summary via email of your results from the testing and the averages of all participants. If you wish to receive your results, please provide your email on the attached consent form where indicated.

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, Aaron Uthoff, *aaron.uthoff@aut.ac.nz*.

Concerns regarding the conduct of the research should be notified to the Executive Secretary of AUTEC, *ethics@aut.ac.nz* , 921 9999 ext 6038.

Whom do I contact for further information about this research?

Please keep this Information Sheet and a copy of the Consent Form for your future reference. You are also able to contact the research team as follows:

Researcher Contact Details:

Chloe Ryan

Sports Performance Research Institute New Zealand (SPRINZ) at AUT Millennium, Auckland University of Technology, 17 Antares Place, Mairangi Bay, Auckland 0632.

Chloe.ryan@xtra.co.nz

Project Supervisor Contact Details:

Dr Aaron Uthoff
Sports Performance Research Institute New Zealand (SPRINZ) at AUT Millennium, Auckland University of Technology, 17 Antares Place, Mairangi Bay, Auckland 0632.
aaron.uthoff@aut.ac.nz

Approved by the Auckland University of Technology Ethics Committee on ***type the date on which the final approval was granted*** *AUTEC Reference number* ***type the AUTEC reference number***

Appendix E Continued: Consent Form

AUT
TE WĀNANGA ARONUI
O TĀMAKI MAKAU RAU

Consent Form

Project title:

The chronic effects of training with wearable resistance on modified 5-0-5 change of direction performance

Project Supervisor: ***Dr Aaron Uthoff***

Researcher: ***Chloe Ryan***

- O I have read and understood the information provided about this research project in the Information Sheet dated January 2023.
- O I have had an opportunity to ask questions and to have them answered.
- O I understand that taking part in this study is voluntary (my choice) and that I may withdraw from the study at any time without being disadvantaged in any way.
- O I understand that if I withdraw from the study then I will be offered the choice between having any data that is identifiable as belonging to me removed or allowing it to continue to be used. However, once the findings have been produced, removal of my data may not be possible.
- O I understand that my data will be confidential and that my results will not be shared with a third party.
- O I am a female between the ages of 16 and 18 years
- O I agree to take part in this research. O yes O no
- O I wish to have my performance results returned to me : O yes O no
- O I agree to have my data stored indefinitely. O yes O no

Participant's signature: ....

Participant's name: ....

Participant's Contact Details (if appropriate):

....

....

....

....

Date:

***Approved by the Auckland University of Technology Ethics Committee on** type the date on which the final approval was granted **AUTEC Reference number** type the AUTEC reference number*

Note: The Participant should retain a copy of this form.

Appendix E Continued: Guardian Consent Form and Student Assent Form

Parent/Guardian Consent Form

Project title:

The chronic effects of training with wearable resistance on modified 5-0-5 change of direction performance

Project Supervisor: ***Dr Aaron Uthoff***

Researcher: ***Chloe Ryan***

- O I have read and understood the information provided about this research project in the Information Sheet dated May 2023.
- O I have had an opportunity to contact the researchers and ask questions.
- O I confirm that my child/children is/are between the ages of 13 and 18 years
- O To the best of my knowledge, I confirm that my child/children is/are not suffering heart disease, high blood pressure, any respiratory condition (mild asthma excluded), any illness or injury that impairs their physical performance.
- O I understand that if I or my child/children withdraw from the study then I/they will be offered the choice between having any data belonging to them removed or allowing it to continue to be used. However, once the findings have been produced, removal of their data may not be possible.
- O If my child/children and/or I withdraw prior to completion of data collection, I understand that upon my request, all relevant information including tapes and transcripts, or parts thereof, will be destroyed.
- O I understand that my child's data will be confidential and that results will not be shared with a third party.
- O I agree to my child taking part in this research. O yes O no
- O I wish to receive a copy of my child/children's results and summary of findings from the research (please tick one) O yes O no
- O I wish to have my child/children's running times accessible to their coach/teacher (please tick one): O yes O no

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

Parent/Guardians signature : ....

Parent/Guardians Name: ....

Parent/Guardians Contact Details :

....

....

....

....

Date:

Approved by the Auckland University of Technology Ethics Committee on type the date on which the final approval was granted AUTEC Reference number 23/25

Note: The Participant should retain a copy of this form.

Assent Form

Project title:

The chronic effects of training with wearable resistance on modified 5-0-5 change of direction performance

Project Supervisor: ***Dr Aaron Uthoff***

Researcher: ***Chloe Ryan***

○ 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 and to have them answered.

○ I am between the ages of 13 and 18 years

○ To the best of my knowledge, I am not suffering from heart disease, high blood pressure, any respiratory condition (mild asthma excluded), any illness or injury that impairs my physical performance.

○ 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.

○ 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 agree to take part in this research

○ I wish to receive a copy of my results and summary of findings from the research (please tick one):

Yes ○ No ○

Participant's signature: ....

Participant's name: ....

Participant Contact Details (if appropriate):

....

....

....

....

Date:

***Approved by the Auckland University of Technology Ethics Committee on** type the date on which the final approval was granted **AUTEC Reference number** 23/25*

Note: The Participant should retain a copy of this form.

APPENDIX F: INFORMATION SHEETS AND CONSENT FORMS

Information sheet for Chapters 4,5 and 7.

Participant Information Sheet

Date Information Sheet Produced:

1st May 2021

Project Title

Acute effects of different Wearable Resistance loading strategies in elite female netball athletes, using a modified 505 test with an advanced diagnostic protocol

An Invitation

My name is Chloe Ryan and I am a Masters student at Auckland University of Technology (AUT). For my master's thesis, I will be conducting a study into the acute effects of different wearable resistance (WR) loading strategies in elite female netball athletes, using a modified 505 test with and advanced diagnostic protocol. The WR being used is a product called Exogen™ exoskeleton (see photos below). Your participation in this study would be greatly valued. It is a voluntary process, and you may withdraw from the research at any time, prior to the completion of the data collection. Participants must have at least 4 years of netball experience and no current injury (within the last 6 months) or medical condition.

Lila™, the producer of Exogen™, will provide Exogen™ suits for use during testing. All results from this study will be anonymous (i.e. without your associated name and personal details) and used to publish for my thesis, research journal publications and/or conference presentations. Your consent to participate in this research will be indicated by your signing and dating the consent form. Signing the consent form indicates that you have read and understood this information sheet, freely give your consent to participate, and that there has been no coercion or inducement to participate.

What is the purpose of this research?

The purpose of this research is to firstly, identify whether the modified 505 test is a reliable test to measure change of direction performance in elite female netball athletes. Secondly, to analyse the changes in changing direction that occur when small amounts of external loading are attached to the body in different locations (upper and lower body). Exogen™ exoskeletons include shorts, sleeveless tops and upper arm, forearm, and calf sleeves to which small (approximately 19 cm long) loads of 50 – 200 g can be attached with Velcro. This research will measure the acute changes in 180-degree change of direction that occur when loads are attached to either your arms or legs. Change of direction will be measured using a modified 505 test, with timing light technology. The findings of this research will be used for the thesis of the primary researcher, Chloe, as well as conference presentations and academic publications.

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

You were identified for this project because you are a healthy elite female netball athlete aged 18-36 years old, with at least 4 years of netball experience. Since you meet these criteria, we would like to invite you to participate in the research.

How do I agree to participate in this research?

If you agree to participate in this study, please complete and sign the attached consent form. This form will be collected in person prior to testing.

Your participation in this research is voluntary (it is your choice) and whether or not you choose to participate will neither advantage nor disadvantage you in any way. You can withdraw from the study at any time. If you choose to withdraw from the study, then you will be offered the choice between having any data belonging to you removed or allowing it to continue to be used. However, once the findings have been produced, removal of any data may not be possible.

What will happen in this research?

As part of this study, you will provide current measures of height, weight and some general information about your health.

These testing sessions will take place at Te Awamutu Events Centre. Each session will be approximately 1 hour long. Data will be collected across three different testing sessions. All information provided to us will be anonymised and recorded in a database only accessible to the researchers involved in this study.

You will complete a standardised warm-up prior to all testing and you will have a recovery period of at least three minutes before each test. You will be randomly split into one of three groups to allow the testing sessions to run as smoothly and quickly as possible. Each testing session will be exactly 7 days apart. The dates of the testing sessions will be Friday the 23rd and 30th of April, and Friday the 7th of May.

Group 1:
Session 1: 2x no load 505 test (each leg) and 2x Upper body loaded 505 tests (each leg).
Session 2: 2 x no load 505 test (each leg) and 2x lower body loaded 505 tests (each leg).
Session 3: 2x no load 505 test (each leg)

Group 2:
Session 1: 2x no load 505 test (each leg)
Session 2: 2x no load 505 test (each leg) and 2x Upper body loaded 505 tests (each leg).
Session 3: 2 x no load 505 test (each leg) and 2x lower body loaded 505 tests (each leg).

Group 3:
Session 1: 2 x no load 505 test (each leg) and 2x lower body loaded 505 tests (each leg).
Session 2: 2x no load 505 test (each leg)
Session 3: 2x no load 505 test (each leg) and 2x Upper body loaded 505 tests (each leg).

Cool Down:
At the end of each session, everyone will complete a group cool down.

2x 20 m jog

1x 20 m walk

5-10 mins of lower body stretching

What are the discomforts and risks?

There should be no significant discomforts or risks associated with this testing beyond those you typically experience during your normal sport testing and training. You will likely experience some shortness of breath and perhaps some lower body muscular soreness in the 48 hours after each testing session.

You will be individually fitted and given the same wearable resistance garments on each occasion. Shorts and vests will be worn over your clothing and arm sleeves can be worn either directly on your skin, or over your own tight-fitting garments. The suits will be washed per the manufacture's guidelines between each use.

How will these discomforts and risks be alleviated?

It is important to stay well hydrated during each testing session and minimise food intake 90 minutes prior to the start of the testing session. You will perform a comprehensive warm-up before the testing session. Full recovery of at least three minutes will be ensured before each test.

What are the benefits?

The research findings will inform us on the acute effects of WR on change of direction performance in female netball athletes. These findings will inform us about different physical qualities and identify which loading strategy may be utilised to enhance specific fitness demands, as well as lead onto future research that determine the training effects of WR on change of direction performance. This could be a potential training tool to help improve overall athletic performance in female netball athletes. As a participant, you will gain information about your current acceleration, deceleration, change of direction and reacceleration capabilities. These results can be used to individualise your on-going strength and conditioning program decisions.

What compensation is available for injury or negligence?

There is no compensation for this research, and you are undertaking voluntarily.

For research conducted in New Zealand; 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.

All efforts have been made to ensure a safe testing environment and methodology. There are appropriate first aid equipment / facilities and trained staff to manage any adverse events during testing.

How will my privacy be protected?

- We will take a number of measures to protect your privacy as much as possible and to ensure your personal details remain confidential.
- 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, the publications will only contain an average of the group's results. 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 obtained from the participants.
- The results from this research, including the de-identified test results (i.e. without your associated name and personal details) will be stored for 6-years in the SPRINZ research database and properly disposed of thereafter. If you choose, your test results may be stored indefinitely in the secured SPRINZ research database.
- The findings of this project will be published in scientific journals, at a conference presentation(s) and in a Masters thesis, but at no stage will you be identifiable. The results will be presented as averages and not individual responses. Your identifiable test results will only be made available to yourself and your sports coach, manager, or doctor (if you agree to this option on the consent form).

What are the costs of participating in this research?

Participating in this research will require approximately 3 hours of your time, split across three sessions.

What opportunity do I have to consider this invitation?

- Please take the necessary time (up to 2 weeks) you need to consider the invitation to participate in this research.
- It is reiterated that your participation in this research is completely voluntary, and you area female athlete between 18 and 36 years of age, healthy and injury free.
- If you require further information about the research topic please feel free to contact myself, Chloe Ryan, or Dr. Aaron Uthoff (details are at the bottom of this information sheet).
- You may withdraw from the study at any time without there being any adverse consequences of any kind.
- You may ask for a copy of your results at any time and you have the option of requesting a report of the research outcomes at the completion of the study.

Will I receive feedback on the results of this research?

We will provide a summary via email of the grouped average results. If you wish to receive your individual results, please select so on the consent form.

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. Aaron Uthoff, *aaron.uthoff@aut.ac.nz*.

Concerns regarding the conduct of the research should be notified to the Executive Secretary of AUTEC, Dr. Carina Meares, *ethics@aut.ac.nz*, 921 9999 ext 6038.

Please keep this Information Sheet and a copy of the Consent Form for your future reference. You are also able to contact the research team as follows:

Researcher Contact Details:

Chloe Ryan

Sports Performance Research Institute New Zealand (SPRINZ) at AUT Millennium, Auckland University of Technology, 17 Antares Place, Mairangi Bay, Auckland 0632.

chloe.ryan@xtra.co.nz

Project Supervisor Contact Details:

Dr Aaron Uthoff
Sports Performance Research Institute New Zealand (SPRINZ) at AUT Millennium, Auckland University of Technology, 17 Antares Place, Mairangi Bay, Auckland 0632.
aaron.uthoff@aut.ac.nz

Approved by the Auckland University of Technology Ethics Committee on type the date on which the final approval was granted AUTEC Reference number type the AUTEC reference number

Consent form for Chapters 4,5 and 7.

AUT

TE WĀNANGA ARONUI O TĀMAKI MAKAU RAU

Consent Form

For use when laboratory or field testing is involved.

Project title: Acute effects of different WR loading strategies in elite female netball athletes, using a modified 505 test with an advanced diagnostic protocol.

Project Supervisor: ***Dr. Aaron Uthoff***

Researcher: ***Chloe Ryan***

By signing this form, you agree to the following statements:

- ○ I have read and understood the information provided about this research project in the Information Sheet dated 1st May 2021.
- ○ I have had an opportunity to ask questions about the research and to have them answered by one of the research team.
- ○ I understand that taking part in this study is voluntary (my choice) and that I may withdraw from the study at any time without being disadvantaged in any way.
- ○ I understand that if I choose to withdraw from the study, there will be no implications related to team selection.
- ○ I understand that if I withdraw from the study then I will be offered the choice between having any data that is identifiable as belonging to me removed or allowing it to continue to be used. However, once the findings have been produced, removal of my data may not be possible.
- ○ I am a female athlete between the ages of 18 and 36 years.
- ○ I am not suffering from heart disease, high blood pressure, any respiratory condition (mild asthma excluded), any illness or injury that impairs my physical performance, or any infection.
- ○ I agree to take part in this research.
- ○ I wish to receive a summary of the research findings (please tick one): Yes○ No○
- ○ I wish to have my performance information accessible to my coach (please tick one): Yes○ No○
- ○ I wish to my performance results stored indefinitely (please tick one): Yes○ No○

Participant's signature: ....

Participant's name: ....

Participant's Contact Details (if appropriate):

....

....

....

....

Date:

Approved by the Auckland University of Technology Ethics Committee on *type the date on which the final approval was granted* ***AUTEC Reference number*** *type the AUTEC reference number*

Note: The Participant should retain a copy of this form.

APPENDIX G: CHAPTER ABSTRACTS

Chapter 2: Traditional and Modified 5-0-5 Change of Direction Test: Normative and Reliability Analysis

Change of direction (COD) ability is an important performance factor in many field and court sports. A common COD maneuver is the 180° turn, which is commonly assessed through the 5-0-5 COD test. Coaches and practitioners need to assess an athlete's COD performance and have access to normative data for these assessments. This review focuses on the traditional and modified 5-0-5 COD test. The 5-0-5 COD performance results have been gathered across 50 different studies and 11 different sports to create sport, sex, and level specific normative data so performance comparisons can be made, which in turn can drive programming to better effect. The reliability of both the traditional and modified 5-0-5 COD tests has been evaluated and discussed. Traditional COD ability of male athletes is better understood given there were 300 male athletes, compared with 62 female athletes. On average, males were 6.03% faster than females. Elite males were 7.78% faster than subelite and novice males, and subelite females were 3.30% faster than novice female athletes. Further research or collation of normative data is needed on female, youth, and elite cohorts to build more comprehensive databases.

Chapter 3: New Perspectives of the Traditional and Modified 5-0-5 Change of Direction Test

Change of direction (COD) ability is considered essential for successful participation in many field and court sports. Several COD models that currently exist identify technique, leg strength qualities, and straight sprint speed as the key determinants of COD performance. This narrative review discusses the original COD model, focusing on specific leg strength qualities (concentric, eccentric, isometric, and reactive strength) and their relationship with 5-0-5 COD performance. It is clear from the existing literature that each of these leg strength qualities contributes to the performance of the 5-0-5 COD test; however, it is unclear which are most at play during the phases of performing a COD. This review introduces a new COD model and a way to split the modified 5-0-5 COD test into 4 distinct phases (acceleration, deceleration, 180B turn, and reacceleration). This new perspective and proposed method of testing provides greater diagnostic value to the modified 5-0-5 COD test and allows coaches and practitioners to be more targeted with feedback and programming to improve COD and sporting performance.

Chapter 4: Sub-phases analysis of the modified 5-0-5 test for better change of direction diagnostics

The aim of this study was to determine whether the utilisation of three timing gates could reliably measure different sub-phases of the modified 5-0-5 COD test, and whether these sub-phases were inter-related. The modified 5-0-5 COD test was adapted, and additional timing gates were placed at 2 m and 4 m, enabling acceleration, deceleration, 180° turn and reacceleration 1 and 2 too be measured independently. Ten elite female netball athletes (age: 24.9 ± 5.0 yrs, height: 180.1 ± 6.5 cm, weight: 81.3 ± 15.0 kg) completed three sessions, consisting of three trials, separated by one week. Pearson correlation coefficients were used to determine the strength of association between variables, and absolute and relative consistency was assessed using coefficients or variation (CV) and intraclass correlation coefficient (ICC), respectively. Correlations between variables ranged from 0.28 to 0.94, with the 180° turn having the greatest shared variance (R2= 88.4%) with total time. The greatest shared variance between sub-phases was 68.9% between deceleration and reacceleration 2 and was the only variable to explain more than 50% of shared variance between sub-phases. All CVs were less than 10% and all ICCs were greater than 0.77 indicating acceptable absolute consistency and ‘good’ to ‘excellent’ relative consistency. These findings suggest firstly that these sub-phases are all independent qualities, and therefore should be measured as such. Secondly, this advanced diagnostic protocol can measure each of these sub-phases reliably.

Chapter 5: Inertial measurement unit analysis for providing greater diagnostic value during the modified 5-0-5 change of direction test

Timing gates are currently the most common piece of equipment for measuring change of direction (COD) performance, however, provide only a total time metric. A better understanding of the kinematics and kinetics during a COD movement beyond total time, would provide coaches with a more comprehensive understanding of COD movement and how it can be improved. Therefore, the aim of this study was to determine the reliability of an inertial measurement unit (IMU) insole for measuring peak acceleration, peak deceleration, maximum speed and ground contact time during a modified 5-0-5 change of direction (COD) test. Additionally, the strength of association between these IMU variables and timing light metrics was explored. Ten elite female netball athletes (24.9 ± 5.0 years, 180.1 ± 6.5 cm, 81.3 ± 15.0 kg) performed a modified 5-0-5 test across three testing occasions. Analysis revealed moderate to excellent relative consistency (ICC = 0.57 – 0.94) and acceptable absolute consistency (CV = 1.8-9.5%). Correlations ranged from 0.04 to 0.95, with peak acceleration having the strongest correlation with total time (r = 0.95). It appears that IMU insole can be used to reliably measure performance during a COD task and provides additional diagnostics beyond time metrics.

Chapter 6: Profiling Change of Direction Ability Using Sub-Phase 5-0-5 Analysis

Change of direction (COD) ability is an important component for most field and court sport athletes. The modified 5-0-5 COD test is a commonly used test to measure 180° COD performance, the diagnostic value of which can be advanced using a multiple-timing light set-up to divide the test into sub-phases. The aim of this research was to determine what proportion of the 5-0-5 COD test was spent performing the 180° COD, whether anthropometry and position of the player influenced the sub-phase performance and provide an alternative approach to improve diagnostics for coaches and practitioners. Ten elite female netball athletes participated in this study. Dual beam timing gates set at 0, 2, and 4 m were used to isolate the phases of the 5-0-5 COD test and quantify COD performance. Independent t-tests were used to assess statistical significance ($p<0.05$) between anthropometry, position, and performance of the sub-phases. Rank-order of sub-phase performance was also conducted to determine individualized performance across phases. The highest percentage of time was spent during the 180° turn and reacceleration 1 phase (~23%). Heavier athletes were significantly slower for deceleration (9.26%), 180° turn (17.1%), reacceleration 2 (7.32%) and total time (8.68%), however no differences were identified between taller and shorter players. A sub-phase rank order table was used to provide diagnostic and training insights that allow more targeted programming to improve COD performance.

Chapter 7: The acute effect of wearable resistance placement on change of direction performance in elite netball players

The aim of this study was to determine the acute effects of wearable resistance forearm (WRf) loading versus shank (WRs) loading on change of direction (COD) performance in netball athletes. Ten elite female netball athletes (age: 24.9 ± 5.0 years, height: 180.1 ± 6.5 cm, weight: 81.3 ± 15.0 kg) participated in this within-subject repeated measures study under three conditions: (1) no load (NL), (2) WRs and (3) WRf, both wearable resistance conditions loaded with 1% body mass on each limb. Athletes performed a modified 5-0-5 COD test with additional timing splits and inertial measurement units placed in their shoes. Total time was significantly longer for both WR conditions with a small effect compared to NL ($p < 0.05$, ES = 0.22–0.25). The greatest differences between WRs and WRf as compared to NL were in the acceleration phase with moderate effect sizes (0–2 m) ($p < 0.05$, ES = −0.67–0.79). Both loading conditions had moderate to large significant effects on peak deceleration (ES = 0.56–0.82) and maximum speed (ES = −0.50–0.60). No significant differences were observed between WR conditions. It appeared that WRs and WRs acutely affected COD performance and therefore might provide a potential training stimulus to elicit positive COD performance adaptations if used over an extended period of time. The choice of overload depended on the musculature that needed training.

Chapter 8: Effects of warming up with lower-body wearable resistance on change of direction, linear speed, and leg power

This 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. Thirty high-school female netball athletes were matched for change of direction (COD) speed and allocated to either WR training or an unloaded group. Both groups performed the same warm-up two times per week for six weeks, 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 broad, lateral and countermovement (CMJ) jump performance. Both groups significantly decreased their 5 m linear sprint times (WRT = -4.41%, effect size [ES] = -1.60; 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 broad 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.

APPENDIX H: ADDITIONAL RESEARCH OUTPUTS

Below are the additional research outputs since starting the PhD:

Ryan, C., Clissold, T., & Winwood, P. (2021). The Quantification, Autoregulation and Reliability of the Stomp as an Osteogenic Exercise. *Sports Injuries and Medicine*, 5, 168.

Ryan, C. M. C., Clissold, T. L., & Winwood, P. W. (2021). The Osteogenic Quantification and Reliability of the Heel Drop and Press up Drop. *International Journal of Science Technology and Society*, 9(6), 294.

Woodbridge, R., **Ryan, C.**, Burkitt, J., Ye-Lee, D., & Cronin, J. (2024). Reliability of a Portable Fixed Dynamometer During Different Isometric Hamstring Assessments. *Applied Sciences, 14*(22), 10202.

Burkitt, J. **Ryan, C.** Ye-Lee, D. & Cronin, J. Intra- and Inter-Session Reliability of Neck Retraction Strength Using a Strain Gauge Device. *Journal of Sport Rehabilitation.* Submitted April 4th, 2024 (In 2nd review).

Green, B., Cronin, J., Cadogan, A. Rumpf, M., & **Ryan, C.** Quantifying Elastic Based Resistance for Shoulder Rehabilitation. *Journal of Bodywork & Movement Therapies.* Submitted February 8th, 2024 (In 2nd review).

Hagley, P., **Ryan, C.**, Yee-Lee, D., & Cronin, J. Reliability of a Portable Fixed Dynamometer During Different Isometric Hamstring Assessments. *Health Care and Technology Letters*. Submitted September 10th, 2024 (In review).

Ryan, C., Cronin, J., Kulczynski, S., & Ireland, J. New perspectives for the resistance training of runners: Flywheel approach. *International Journal of Strength and Conditioning*. Submitted June 15th, 2024 (In 2nd review).

The End