DOES THE IMPLEMENTATION OF RAPID DECELERATION TRAINING IMPROVE CHANGE OF DIRECTION PERFORMANCE IN RUGBY PLAYERS?

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Abstract

Agility and change of direction (COD) are distinct but crucial skills for team sport athletes. As athletes develop different performance aspects, the ability to control the body during COD is altered. Unplanned rapid COD, particularly during the deceleration phase, are the most likely cause of non-contact injuries in team sports. There is little previous research on deceleration to provide guidance for this component of performance, particularly with reference to rugby union. The aim of this thesis was to; 1) to determine if a period of deceleration training would result in improved COD performance in rugby players; 2) determine a suitable deceleration performance index that can be used in the field to assess deceleration ability. Methods: Seven male club level (age: 24.4 ± 7.4 years; height: 181 ± 7cm; mass: 87.5 ± 7.7kg; rugby experience: 10.9 ± 5.5 years) and five female regional level (age: 23 ± 5.7 years, mass: 71.3 ± 13.8kg, rugby experience: 6.8 ± 5.9 years) rugby players were recruited during a period of pre-season training. During one single session, the male group performed 10m speed, horizontal jump, vertical jump, bounce drop jump, 505 COD test, One Repetition Maximum (1RM) squat as part of pre-season testing. The female group completed the 505 COD test only. Participants then completed the six week training intervention which consisted of a 20-30 minute warm-up protocol twice per week. The protocol focused on deceleration drills and the execution of rapid deceleration efforts. All performance tests were repeated following the training intervention. A Paired T-Test, Effect Size (ES) and Hedges' g ES calculations were used to analyse differences pre to post intervention. Smallest Worthwhile Change calculations were calculated to detect meaningful change pre-post intervention. Pearson Product Moment Correlation data using pooled pre and post intervention data determined relationships between performance tests and 505 COD performance. Results: Nine out of twelve participants improved or maintained performance in the 505 COD test (Group: n=12, 0.1 ± 2.8%, ES=0.09, Female: n=5, 0.06 ± 3.3%, ES=0.08, Male: n=7, 0.06 ± 2.4%, ES=0.10). There were significant improvements in jump performance, particularly bilateral vertical (ES=0.13), right leg (ES=0.37), and left leg (ES=0.83) vertical jumping pre to post intervention. There were very high correlations between relative strength (r=0.710) and 1RM squat (r=0.546) and 505 COD performance. High correlations between bilateral horizontal jump (r=0.543), and right leg horizontal jump (r=0.603), bilateral vertical jumps (r=0.606), right leg vertical jump (r=0.591) and left leg vertical jump (r=0.557) and 505 COD performance were found. A Deceleration Index has been proposed that provides accurate description of performance changes with regard to COD and momentum. Conclusion: Practicing COD movements and drills, specifically the deceleration component rapidly from high velocity running can improve COD performance and contributing sub qualities of this ability in rugby players. Practical application: Introducing deceleration drills as part of a warm-up for team trainings will provide enough stimulus to improve deceleration capacity and COD and agility performance. Drills should be progressed as players become more skilled, being able to decelerate from increasing speeds within shorter distances.

Key words: Deceleration, Change of direction, Acceleration, Agility, Rugby Union

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Attestation of Authorship

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

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Ethics Approval

Ethics approval for this thesis was granted by Auckland University of Technology Ethics Committee (AUTEC) on 24 July 2017; ethics application number: 17/233.

Chapter One

Introduction

Background

Agility and change of direction (COD) are crucial skills for team sport athletes (Dawes & Roozen, 2012; Dos'Santos, Thomas, Comfort, & Jones, 2018; Gleason, Kramer, & Stone, 2015; Hart, Spiteri, Lockie, Nimphius, & Newton, 2014; Holmberg, 2009; Jones, Thomas, Dos'Santos, McMahon, & Graham-Smith, 2017; Lockie, Schultz, Callaghan, & Jeffriess, 2013; Nimphius, Callaghan, Bezodis, & Lockie, 2018; Shimokochi, Ide, Kokubu, & Nakaoji, 2013; Spiteri, Newton, Binetti, Hart, & Sheppard, 2015; Tominaga, Ishii, Ueda, & Kurokawa, 2016; Watts, 2015; Young, 2006). The deceleration phase of COD is where breaking forces are applied to slow momentum, and control the body in preparation for a COD manoeuvre (Graham-Smith, Rumpf, & Jones, 2018; Jones et al., 2017; Kovacs, Roetert, & Ellenbecker, 2008). The faster a player can come to a stop to re-accelerate in another direction, the more competitive or reactive they can be on the field (Baker & Newton, 2008; Dalen, Jorgen, Gertjan, Geir Harvard, & Ulrik, 2016; Dawes & Roozen, 2012; Delaney et al., 2016; Gabbett, Kelly, & Sheppard, 2008; Gleason et al., 2015; Graham-Smith et al., 2018; Green, Blake, & Caulfield, 2011; Griffith, 2005; Harper, Jordan, & Kiely, 2018; Hart et al., 2014; Hewit, Cronin, & Hume, 2013; Jones et al., 2017; Kovacs et al., 2008; Lockie et al., 2013; Shimokochi et al., 2013; Spiteri et al., 2015; Taber, Bellon, Abbot, & Bingham, 2016; Tominaga et al., 2016). Often, little time is often spent on improving the ability to decelerate as an explicit skill to improve COD and agility performance. This could be likened to the way acceleration ability is emphasised for improving sprint speed. With a large emphasis on acceleration, neglecting deceleration ability as a training focus could decrease athletic performance and increase risk of injury (Holmberg, 2009; Jacobs, Uhl, Mattacola, Shapiro, & Rayens, 2007; Kovacs et al., 2008; Shimokochi et al., 2013; Smith, Sizer, & James, 2009; Tominaga et al., 2016). As athletes develop different performance aspects such as strength, speed and body composition, the ability to control the body through a COD is altered. Unplanned, rapid changes in direction are the most likely cause of non-contact injuries like anterior cruciate ligament (ACL) failure in team sports (Holmberg, 2009; Jacobs et al., 2007; Kovacs et al., 2008; Shimokochi et al., 2013; Smith et al., 2009; Tominaga et al., 2016). An athlete who can subconsciously move using superior movement strategies may feel as if they have more time to react to a game environment (Holmberg, 2009; Kovacs et al., 2008). It has been reported that a determining factor between higher level team sport athletes during COD tasks are higher eccentric strength capacities and optimised body composition to produce greater momentum compared to other athletes with the same sprint speed (Dalen et al., 2016; Dawes & Roozen, 2012; Delaney et al., 2016; Gabbett et al., 2008; Green et al., 2011; Harper et al., 2018; Hewit, Cronin, & Hume, 2012; Jones et al., 2017; Keiner, Sander, Wirth, & Schmidtbleicher, 2014; Spiteri et al., 2015; Watts, 2015). This eccentric strength may better enable players to control greater momentum and decelerate faster within a shorter distance (Dalen et al., 2016; Dawes & Roozen, 2012; Delaney et al., 2016; Gabbett et al., 2008; Green et al., 2011; Harper et al., 2018; Hewit et al., 2012; Jones et al., 2017; Keiner et al., 2014; Spiteri et al., 2015; Watts, 2015). This is valuable for on field performance in time crucial sports such as Rugby Sevens (Dalen et al., 2016; Delaney et al., 2016; Gabbett et al., 2008; Green et al., 2011; Harper et al., 2018; Jones et al., 2017; Keiner et al., 2014; Spiteri et al., 2015; Watts, 2015). An investigation into rapid deceleration from high velocity sprint efforts could be advantageous to improve the way athletes prepare for the demands of rugby codes, especially with the growth of Rugby Sevens as a mainstream global sport.

Several tests are commonly used to assess agility and COD performance (Dawes & Roozen, 2012; Jones et al., 2017; Joyce & Lewindon, 2014). However, the specificity of these tests to on field performance is a topic of debate in the literature (Dawes & Roozen, 2012; Hart et al., 2014; Nimphius, 2014; Nimphius et al., 2018; Nimphius, Callaghan, Spiteri, & Lockie, 2016; Sheppard, Dawes, Jeffreys, Spiteri, & Nimphius, 2014). The 505 COD test, T-Test, American Football League (AFL) Agility test, Illinois Agility test and several others are often used in team sport testing batteries (Dawes & Roozen, 2012; Joyce & Lewindon, 2014). Each of these tests feature varying numbers of straight line sprinting and COD tasks, with different expected times for completion (Baker & Newton, 2008; Dawes & Roozen, 2012; Jones et al., 2017).

The 505 COD test will be a focus of this thesis, and was selected because of its demanding deceleration component from a high velocity sprint (Lockie, Dawes, & Jones, 2018; Nimphius, 2014; Nimphius et al., 2018; Nimphius et al., 2016). Other tests that are commonly used to assess COD performance will be discussed in further detail in Chapter Two. In addition to the 505 COD test, lower body maximal and relative strength, horizontal and vertical jumping, 30cm bounce drop jump, as well as 10m sprint were assessed to understand the relationship between COD and the sub-qualities associated with this component of performance.

Significance of Thesis

There is little research that treats deceleration as an explicit trainable skill available to guide strength and conditioning practice around COD performance and team sport preparation. Much of the literature explains deceleration as an inherent component of COD (Kovacs et al., 2008), but little time is spent on improving this component as coaches may prioritise speed training. Therefore, this research aimed to determine if training the deceleration phase improves COD performance. This research will provide insight to understand how practitioners approach COD training in team sports, and how this can be integrated into a training session. Integrating this training intervention as a 15-20 minute warm-up protocol will mean that participants are exposed to this stimulus regularly. Previous recommendations for improving this component of performance suggest that regular 15 minute COD training will elicit a training adaptation (Joyce & Lewindon, 2014). Regular exposure to the warm-up protocol long term will allow for skill acquisition and competency with deceleration and allow for increased complexity and loading progressions (Joyce & Lewindon, 2014). A deeper understanding of deceleration during COD and the underpinning sub-qualities that can be trained may provide more appropriate development and progression of athletes as experience and game intensity increases. New insights to deceleration training may also provide a different approach to plan for return to play for athletes who have suffered injury and are required to perform maximal rapid deceleration as part of their sport.

Research Question

Does the improvement of deceleration performance improve COD performance using the 505 COD test?

Study Aims

1) Determine whether a period of deceleration training will result in improved COD performance in rugby players using the 505 COD test;
2) Confirm the physical qualities associated with deceleration and 505 COD performance;
2) Propose a suitable deceleration performance index (DI) that can be used in the field to assess deceleration ability.

Study Hypotheses

1) Performance in the 505 COD test will improve after a period of deceleration specific training.
2) Superior lower body strength, speed, and reactive strength will be positively related to superior deceleration and/or COD performance, and may improve in relation to the training protocol.
3) A Deceleration Index (DI) could be developed using key performance measures.

Thesis Organisation

This thesis investigated the efficacy of a rapid deceleration training protocol for improving COD performance. This thesis adheres to pathway one, with chapters consisting of an introduction, literature review, results, discussion, conclusion and appendix.

Chapter one includes an introduction to the research, outlining the overview of the thesis, and provides context to the topic. Chapter two includes a literature review, further clarifying the context of the thesis and introduces deceleration as an explicit component of performance. This chapter has a specific focus and examination of the importance to team sport athletes, in particular athletes participating in rugby codes. Chapter two is concluded by suggestions for future study on the topic, with possible training applications. Chapter three outlines the methods of the study: a longitudinal experimental study investigating pre and post training intervention performance measures. It also provides an overview for understanding as to whether specific deceleration drills and rapid deceleration efforts from sprint speed will improve 505 COD time and/or associated performance measures. Chapter four presents the results of the study pre and post training intervention, in addition to exploring the relationships between variables. Finally, Chapter five, discusses the results, relationships and concepts explained in previous chapters, introduces the concept of a DI, and suggests practical applications based on the thesis findings.

Chapter Two

Literature Review

Literature Search

To obtain relevant articles a search was conducted using the AUT Library eJournal databases and Google Scholar using key words “deceleration”, “change of direction”, “Agility”, “505”, “T-Test”, “rugby”, “reactive strength”, “team sport”, “speed”, “AFL Agility”, “acceleration”, “GPS”, “kinetic”, “kinematic”, “Breaking/braking force”, “eccentric”, “fatigue”, “GPS”.

Introduction

In team sports, agility is an important ability for athletes (Bourgeois, Gamble, Gill, & McGuigan, 2017; Dawes & Roozen, 2012; Dos'Santos, Thomas, Comfort, et al., 2018; Gleason et al., 2015; Graham-Smith et al., 2018; Green et al., 2011; Hart et al., 2014; Hewit, Cronin, Button, & Hume, 2011; Holmberg, 2009; Jones et al., 2017; Lockie et al., 2013; Nimphius et al., 2018; Shimokochi et al., 2013; Spiteri et al., 2015; Tominaga et al., 2016; Watts, 2015; Young, 2006). Throughout the literature there have been discrepancies between what agility means and how it should be implemented into a training program (Gleason et al., 2015; Nimphius et al., 2018; Sheppard et al., 2014; Watts, 2015; Young, 2006). A comprehensive definition of agility encompasses both the physical requirements of altering body positions and directions of force application, termed COD, as well as the cognitive aspects required to react to an unplanned training drill or competitive environment (Dawes & Roozen, 2012; Gleason et al., 2015; Jones et al., 2017; Lockie et al., 2018; Nimphius et al., 2018; Sheppard et al., 2014; Watts, 2015; Young, 2006; Young, James, & Montgomery, 2002). When performing agility tasks an athlete is expected to maximally accelerate, decelerate, rapidly change direction, control momentum and re-accelerate in the intended direction (Bourgeois et al., 2017; Dawes & Roozen, 2012; Delaney et al., 2016; Gleason et al., 2015; Graham-Smith et al., 2018; Jones et al., 2017; Lockie, Callaghan, & Jeffriess, 2015; Lockie et al., 2013; Nimphius et al., 2018; Sheppard et al., 2014; Shimokochi et al., 2013; Thomas, Dos'Santos, Comfort, & Jones, 2018; Watts, 2015; Young, 2006; Young et al., 2002). Athletes are required to do all of this while searching for and responding to relevant external stimuli, effectively and repeatedly, in order to gain competitive advantage (Gleason et al., 2015; Hart et al., 2014; Holmberg, 2009; Lockie et al., 2013; Nimphius et al., 2018; Shimokochi et al., 2013; Spiteri et al., 2015; Tominaga et al., 2016; Watts, 2015; Young, 2006). These are separate components that can be learnt separately in the early learning stages, but should be combined as the athlete improves (Sheppard et al., 2014). Deceleration skill is crucial to allow for rapid COD, and improving this ability could increase competitive advantage (Thomas et al., 2018). Reducing the amount of time or distance required to stop and change direction may have tremendous impact on speeding up game play, especially in sports that are time crucial, where significant advantage can be made within seconds (Kovacs et al., 2008; Lockie et al., 2013).

Purpose of the Review

This review will largely focus on the physical components of agility, specifically to understand the importance of the deceleration skill to improve COD ability. Increased deceleration performance could increase an athlete's ability to direct attentional focus on searching for and reacting to relevant external stimuli in the context of a game (Holmberg, 2009). An attempt will be made to explain the relevance of deceleration skill in the context of rugby codes. There appears to be a lack of technical teaching models for training the deceleration component of the agility skill and research comparing the effectiveness of specific agility training programs, which may be why deceleration is underutilised and overlooked as a key skill to develop (Gleason et al., 2015; Holmberg, 2009; Young et al., 2002). Using a deterministic model we can isolate the components and sub-components that underpin the agility skill (Joyce & Lewindon, 2014; Nimphius, 2014; Watts, 2015; Young, 2006). Athletes should be progressed using a dynamical systems theory approach as the athlete becomes more proficient (Joyce & Lewindon, 2014; Nimphius, 2014; Young, 2006). Developing athlete agility and COD skill not only allows athletes to gain positional advantage in a game, it may also serve to prevent injury in planned and unplanned COD (Holmberg, 2009; Watts, 2015). It is important to note that COD tests differ significantly from agility tests, and performance in COD and agility tests of different types should not be compared (Joyce & Lewindon, 2014; Nimphius, 2014). COD primarily focuses on the physical abilities required to change direction, excluding the skill of reading and reacting to the environment during an agility task. It is important to differentiate between these two abilities and understand that good COD performances may not reflect a good performance in an agility task and vice versa (Gabbett et al., 2008). Although these abilities are connected, they should be considered as separate skills when using COD and agility tasks for assessment or team selection purposes (Gabbett et al., 2008; Gleason et al., 2015; Holmberg, 2009; Joyce & Lewindon, 2014; Watts, 2015).

Deceleration is rarely looked at in a training program as an explicit component of physical ability apart from its inherent inclusion in a COD or agility task. Improvement in speed or fitness is usually the main focus for running based training programs, it needs to be understood if it would be valuable to treat deceleration as a separate focus, and to what extent it can be trained. This literature review has been divided into sections identified by the subheadings, which focus on injury, components of COD performance, testing COD performance, rugby specific analysis, and future considerations and conclusions based on the findings of this literature search.

Injury

Research suggests that a majority of non-contact injuries experienced during team sport game play are a result of unplanned COD manoeuvres, specifically while actively lengthening muscle during the deceleration component of COD/agility (Dos'Santos, Thomas, Comfort, et al., 2018; Holmberg, 2009; Jacobs et al., 2007; Kovacs et al., 2008; Shimokochi et al., 2013; Smith et al., 2009; Tominaga et al., 2016). It is important to understand safe movement strategies for deceleration in preparation to change direction, especially lateral variations of this, like cutting or sidestepping (Dos'Santos, Thomas, Comfort, et al., 2018; Shimokochi et al., 2013). Injury can occur during these circumstances when the body is not in an optimal position to decelerate and subsequently change direction (Dos'Santos, Thomas, Comfort, et al., 2018; Kovacs et al., 2008). If an athlete’s technique is suboptimal while decelerating, the dissipation of absorbed forces across joints and through muscle connective tissues will not be effective (Young, 2006). Poor deceleration ability could result in uncontrolled rotation over the centre of mass (COM), causing instability or compromised absorption ability causing injury (Young, 2006). The angle and approach velocity while executing a COD determines the difficulty of the task, and contributes to potential risk of injury (Dos'Santos, Thomas, Comfort, et al., 2018). The sharper the required turn, the higher loading at the knee and energetic cost, which is related to the breakdown of optimal mechanics for COD that result in injury (Dos'Santos, Thomas, Comfort, et al., 2018). To reduce risk of injury an athlete must be capable of absorbing breaking forces specific to their own momentum, sprint velocity and specificity of COD angle for their sport (Dos'Santos, Thomas, Comfort, et al., 2018). An athlete who cannot control their momentum, and apply breaking forces to decelerate effectively will be less competitive during game contexts and testing sessions, and likely increase risk of injury (Kovacs et al., 2008).

Injury to the ACL is the most common non-contact injury in team sports, and occurs 2-8 times more frequently in women than men (Smith et al., 2009; Tominaga et al., 2016). The cause of the ACL injury is multifaceted, with 70% of ACL tears are non-contact injuries, which almost always occurs during a rapid unplanned deceleration or COD (Colby et al., 2000; Smith et al., 2009; Tominaga et al., 2016). When investigated through video analysis, these ACL injuries usually occurred at foot strike with the knee close to full extension, with excessive dynamic valgus collapse (Smith et al., 2009). This circumstance is usually due to insufficient eccentric strength to protect joint structures (Kovacs et al., 2008). Athletes who can approach a turn at a high velocity and absorb high levels of breaking forces are more effective at reducing load at the knee, reducing injury risk, and increasing COD performance (Dos'Santos, Thomas, Comfort, et al., 2018). High levels of eccentric strength are vital for optimising deceleration performance and preparing the musculature supporting the knee for rapid and high force absorption (Dos'Santos, Thomas, Comfort, et al., 2018). Higher eccentric strength has been found to be a determining factor in superior COD performance due to more effective deceleration and breaking force application (Hewit et al., 2012; Jones et al., 2017).

Eccentric training not only improves deceleration performance, but it also aids in injury prevention (Kovacs et al., 2008). The protective advantage gained from eccentric exercise is that there is a positive effect on altering the length-tension relationship (Kovacs et al., 2008). This means that the optimum length of peak tension occurs at longer muscle lengths, therefore more muscle tension can be tolerated before risk of injury i.e. tendon rupture (Kovacs et al., 2008). Under fatigue knee strategies to stop, land and control the body during deceleration and execution of COD task are modified. The musculature surrounding the knee joint has an altered ability to protect the joint under fatigue (Smith et al., 2009; Tominaga et al., 2016). A number of changes are seen when neuromuscular control is compromised: reduced electromyographic (EMG) activity, poor joint kinematics and reduced ground reaction force (GRF) magnitudes (Smith et al., 2009). These changes affect lower extremity ‘stiffness’ during landing and other running or COD patterns (Smith et al., 2009). Maintaining lower limb joint stiffness is extremely important for utilising the stretch shorten cycle (SSC) optimally for superior performance with running speed and executing COD manoeuvres (Smith et al., 2009). Reduced stiffness and neuromuscular control while executing landing during running and COD may increase an athlete’s risk of injury (Smith et al., 2009). This is exacerbated when game demands exceed the intensity performed in training, or neglecting to prioritise deceleration or COD mechanics in the training plan, leaving the athlete susceptible to injury when in a competitive and unplanned environment.

Smith et al. (2009) investigated the effect of fatigue on knee motion during landing to understand why women are 2-8 times more likely to suffer from ACL injury than men. In this particular study, a repeated isometric contraction from a 60 degree knee flexion squat position while pulling a bar chained to the floor was used to induce fatigue (Smith et al., 2009). The desired level of fatigue was achieved when participants were only able to perform 50% or less force of their initial maximum contraction for the exercise (Smith et al., 2009). To assess the differences in movement strategies used by each gender, 10 bilateral depth jumps from a 50cm platform onto a force platform were performed pre fatigue, post fatigue only five jumps were required (Smith et al., 2009). Analysis of fatigued landings at the individual level indicated that the fatigued movement strategies were indicative of movement strategies that increase risk of ACL injury (Smith et al., 2009). While under fatigue, subjects increased valgus and/or collapse, both of which can load the ACL significantly, particularly in unplanned cutting manoeuvres (Dos'Santos, Thomas, Comfort, et al., 2018; Smith et al., 2009). In the 30° knee flexion position the quadriceps muscles provide anterior shear force, and while fatigued the hamstrings have a reduced capacity to co-contract to protect the knee joint and surrounding ligament systems (Smith et al., 2009). It has been suggested that the increased anterior shearing forces at the ACL while under fatigue at 30-45° of knee flexion created by the quadriceps muscle are not able to reach a great enough magnitude to be the sole cause of an ACL failure (Smith et al., 2009). However, coupled with the hamstrings reduced capacity to co-contract and protect the knee joint in frontal plane motions, it is likely that the combination of the two is the reason for increased load on the ACL causing failure (Smith et al., 2009). Smith et al. (2009) suggest that women rely more on their quadriceps than hamstrings to avoid anterior tibial translation while fatigued, which further increases strain on the ACL (Smith et al., 2009). Agility and plyometric exercise have been suggested to improve functional stability of the knee by reducing anterior tibial translation and dynamic valgus (Smith, et al., 2009). Fatigue does alter the neuromuscular response to anterior tibial translation, therefore, it may play a role in the pathomechanics of knee injuries (Smith et al., 2009). The unplanned nature of on field cutting tasks further exacerbates the risk of injury with significantly higher loads placed on the knee joint structures, increasing the risk of knee ligament injury due to insufficient time available to make necessary postural adjustments (Young, 2006). Being able to respond more quickly to external stimuli during gameplay may not only enhance performance, but also reduce injury risk (Dos'Santos, Thomas, Comfort, et al., 2018; Young, 2006). Improving physical components of agility will allow attentional focus to be directed towards scanning for and reacting to relevant the external stimuli (Gleason et al., 2015; Holmberg, 2009). Within the scope of the Smith et al. (2009) study there were no significant differences between genders with movement strategies for landing under fatigue (Smith et al., 2009). Individual analysis provided more information on alteration of movement strategies, from non-fatigued to fatigued strategies to predict injury (Smith et al., 2009). This suggests that an individual approach should be used with team sport athletes that have a need for COD skills.

Additionally, the larger the performance deficit between limbs the higher the risk of injury when having to rely on the non-dominant side for executing a COD (Bishop, Read, Chavda, & Turner, 2016; Hart et al., 2014). This deficit could be identified through a number of measures, for example: vertical and horizontal jumping, unilateral reactive strength, eccentric strength, time to execute a turn off each leg and time to complete a task that favours one limb at a time (Bishop et al., 2016; Thomas et al., 2018). Collecting unilateral performance data will aid in developing strength and conditioning programs, and also ensure that steps are in place to monitor athletes with large deficits and attempt to reduce this (Hart et al., 2014). Asymmetries between single leg performance measures, especially when exceeding 10% increase risk of injury (Hart et al., 2014). Bishop et al. (2016) has analysed the different equations used to quantify limb asymmetry. Single leg counter movement jumps have been found to be reliable measures to determine between limb deficiency (Bishop et al., 2016). The equations used to calculate this are inconsistent and often produce different values for differences between limbs depending on which limb performance comes first in the equation (Bishop et al., 2016). Bishop et al. (2016) found the equation devised by Zifchock, Davis, Higginson and Royer (2008) to be the most reliable asymmetry calculation, which does not favour either value in the calculation. This finding is important for assessing true limb asymmetry to decide whether or not strengthening is required for both performance enhancement in single leg tasks like running and jumping, and assessing injured limbs in comparison to non-injured limbs (Bishop et al., 2016; Zifchock, Davis, Higginson, & Royer, 2008).

Deterministic Models of Agility, Change of Direction and Deceleration

The critical factors underpinning agility performance have been presented in Table 2.1, based on models published by Joyce and Lewindon (2014), Young (2006) and Watts (2015). This incorporates the physical and cognitive components of agility. The responsibility of improving COD and ability falls on the strength and conditioning practitioner, however coaches do not always have a complete understanding of what this entails (Holmberg, 2009). This is where some disconnect between interpretation of the skill, and training methods to improve agility, COD and deceleration performance may occur. By breaking down the COD skill into the components and sub-components seen in Table 2.1 coaches can eliminate any other non-productive elements in training and focus on those that will contribute to improved COD (Holmberg, 2009). Within the COD skill there are three main components, technique, straight sprinting speed, and leg muscle qualities (Dawes & Roozen, 2012; Joyce & Lewindon, 2014; Watts, 2015; Young, 2006). Strength and conditioning coaches can improve agility by targeting the components that underpin this skill: speed, acceleration, deceleration, COD speed, and the qualities that underpin these 'sub-components', such as strength, stability, mobility to identify areas needing improvement (Dawes

& Roozen, 2012; Joyce & Lewindon, 2014; Sheppard et al., 2014; Young, 2006). The deterministic model of agility performance suggests that to improve COD speed we can influence technique and leg muscle qualities
(Dawes & Roozen, 2012; Joyce & Lewindon, 2014; Watts, 2015; Young, 2006). Technique based factors that can be monitored and potentially adjusted include foot placement, stride adjustments, body lean (Dawes & Roozen, 2012; Joyce & Lewindon, 2014; Watts, 2015; Young, 2006). Trainable leg muscle qualities incorporated strength, power, muscle imbalance and reactive strength (Dawes & Roozen, 2012; Joyce & Lewindon, 2014; Watts, 2015; Young, 2006).

Table 2.1 Deterministic Model of Agility Performance adapted from Joyce and Lewindon (2014), Watts (2015) and Young (2006)

Agility							
Change of Direction Speed				Perceptual and Decision Making Factors			
Anthropometry	Leg muscle qualities	Straight sprinting speed	Technique	Visual Scanning	Anticipation	Pattern Recognition	Knowledge Of Situations
	Strength and power		*Foot placement*				
	Left-right muscle imbalance		*Adjustment of strides to accelerate and decelerate*				
	Reactive strength		*Body lean and posture*				

Italics indicates a subquality of the above component of agility

Kovacs et al. (2008) further break down this model of agility by depicting a deterministic model of deceleration. Table 2.2 describes the components needed to be learnt by athletes to become proficient decelerators (Kovacs et al., 2008). A deterministic model is used to analyse and evaluate the key components of a skill, and highlight the areas that should be looked at for training (Kovacs et al., 2008). There are three components that deceleration can be broken down into, musculo-skeletal, neural and technique (Kovacs et al., 2008; Young, 2006). Kovacs et al. (2008) further describe four main sub-components to focus on to improve deceleration as dynamic balance, eccentric strength, power and reactive strength (Table 2.2). These are interrelated components that can fall within multiple components of deceleration described in Table 2.2.

Table 2.2 Deterministic Model Of Deceleration, adapted from Kovacs et al. (2008)

Deceleration							
Technique			Neural		Musculo-Skeletal		
Upper Body Position	Lower Body Position	Coordinated Movements	Proprioceptors	Motor Neuron Recruitment	**Power**	Flexibility	Strength
Efficient joint angles	*Efficient joint angles*	*Correct sequencing of body segments*	*Dynamic balance*		*Rate of force development*	***Dynamic balance***	***Eccentric strength***
	Lower COM		*Muscle spindles*		***Reactive strength***		***Reactive strength***
			Golgi tendon organs				

Bold indicates the four major components of deceleration described by Kovacs et al. (2008), *Italics* indicates a subquality of the above component of deceleration. COM=Centre of Mass.

This is a complex model that is extremely useful for understanding the different properties that can be trained to result in an improved deceleration performance, and improved COD and agility performance (Kovacs et al., 2008). The dynamical systems theory approach is important to understand when implementing training for COD and agility (Holmberg, 2009; Joyce & Lewindon, 2014). Isolating the deceleration skill and the components involved is one way that we can engrain stable and robust movement pathways for deceleration, and thereafter introduce noise to the skill to adapt to variable and unplanned environments (Holmberg, 2009; Joyce & Lewindon, 2014).

Leg muscle qualities are one important branch in the deterministic model of agility performance (Table 2.1), but they are not solely responsible for effective COD and agility performance (Joyce & Lewindon, 2014; Watts, 2015; Young, 2006). An athlete who can apply large amounts of force into the ground, but is not proficient at adopting the desired body positions to move in the intended direction will be unlikely to have efficient propulsion in the intended direction (Joyce & Lewindon, 2014; Watts, 2015; Young, 2006). Instead energy will be lost by the body rather than transmitted through the body for motion (Joyce & Lewindon, 2014; Watts, 2015; Young, 2006). Similarly, if the body is not in a desirable position while decelerating, the dissipation of absorbed forces across joints and through muscle connective tissues will not be effective (Watts, 2015; Young, 2006). This could result in an uncontrolled rotation over the COM causing instability, or compromised absorption ability causing injury (Joyce & Lewindon, 2014; Young, 2006). The deterministic model of agility performance links strength, power and reactive strength as important trainable leg muscle qualities that can influence COD speed (Joyce & Lewindon, 2014; Watts, 2015; Young, 2006).

Dynamical Systems Theory: Agility, Change of Direction and Deceleration

Players who are better at agility are sometimes but not always faster, but usually possess superior decision making skills (Dawes & Roozen, 2012; Joyce & Lewindon, 2014; Watts, 2015). Like agility, deceleration is a trainable motor skill and should be treated as such, with appropriate rest and loading parameters as per the dynamical systems theory of skill learning (Holmberg, 2009; Joyce & Lewindon, 2014; Kovacs et al., 2008). Isolating the mechanics as part of the deterministic model of agility or deceleration, and reducing noise during the skill learning period will strengthen the movement strategies to decelerate effectively (Holmberg, 2009; Joyce & Lewindon, 2014; Kovacs et al., 2008). When an athlete becomes more skilled at executing these movements, the athlete will be more responsive to the external stimuli (Dawes & Roozen, 2012; Holmberg, 2009). Attentional focus can then be directed towards the cognitive aspects, allowing the athlete to feel as if they have more time to react (Dawes & Roozen, 2012; Holmberg, 2009; Joyce & Lewindon, 2014; Kovacs et al., 2008). Introducing too many tasks within one drill with athletes who are not skilled in agility will overload the sensory when trying to learn how to execute the physical components required to react effectively (Holmberg, 2009; Joyce & Lewindon, 2014).

Dynamical systems theory suggests that the number of degrees of freedom associated with a task are reduced as the development of a movement pathway becomes more stable (Holmberg, 2009; Joyce & Lewindon, 2014). Once a movement strategy is stable, variability in the movement context can be introduced to make the movement more complex (Dawes & Roozen, 2012; Holmberg, 2009; Joyce & Lewindon, 2014). The initial stabilization of a movement strategy, followed by increasing variability allows the athlete to be flexible with selection of movement, but remain stable in execution and maximise performance while reducing risk of injury (Dawes &

Roozen, 2012; Holmberg, 2009; Joyce & Lewindon, 2014). COD and agility tasks are multidimensional skills, requiring the ability to control different variables during the skill execution (Dawes & Roozen, 2012; Joyce & Lewindon, 2014; Kovacs et al., 2008; Spiteri et al., 2015; Young, 2006). Successful COD and agility performance is determined by the selection of a movement strategy based on relevant external stimuli (Holmberg, 2009; Joyce & Lewindon, 2014). To be able to select and adjust movement based on external feedback is an important concept to remember when developing athletes to be robust and able to perform stable movements in varied environments (Dawes & Roozen, 2012; Holmberg, 2009; Joyce & Lewindon, 2014).

Agility training sessions need to be designed in accordance with the level of the athlete and specificity to their sport and position (Dawes & Roozen, 2012; Gleason et al., 2015; Holmberg, 2009). Training for COD that relies on structured movement patterns, for example using one or two drills in the same direction repeatedly, will only benefit the athlete who has to perform a structured running pattern with no external stimuli dictating movement responses (Dawes & Roozen, 2012; Holmberg, 2009; Joyce & Lewindon, 2014). Once the movement has been established and refined, the athlete can then progress to more complex tasks, integrating multiple skills or reaction drills (Dawes & Roozen, 2012; Gleason et al., 2015; Holmberg, 2009; Joyce & Lewindon, 2014). Holmberg (2009) uses the term contextual interference (CI) to describe the complexity of a task. A low CI is associated with movements executed in isolation, i.e. practicing to decelerate to a stop. A high CI is the execution of multiple skills or movement, i.e. decelerating to a COD with a cognitive component or competitive component introduced, or additional physical components (Dawes & Roozen, 2012; Gleason et al., 2015; Holmberg, 2009). Low CI tasks allow the learner to refine technique and make adjustments and stabilise a movement strategy, a high CI task is where movement variability is introduced, attention is taken away from focusing solely on body position, reacting to a stimuli when required (Dawes & Roozen, 2012; Gleason et al., 2015; Holmberg, 2009). The benefit that refining movement strategies before exposing the athlete to complex progressions could be that on the field the athlete can more closely focus on cognitive aspects of the game, knowing that the body is prepared to execute rapid changes in direction to react to relevant stimuli (Holmberg, 2009). This refinement may mean that the athlete feels as if they have more time to make decisions (Dawes & Roozen, 2012; Holmberg, 2009; Joyce & Lewindon, 2014). Limited time to react to external stimuli in unplanned COD has been reported as one of the factors responsible for increased injury risk on the field (Holmberg, 2009).

Change of Direction and Deceleration Technique

An ideal running posture for a track sprinter compared to that for a rugby player who has to change direction will be different (Young, 2006; Young et al., 2002). The need to react to constant external stimuli and maintain a body position that can meet the demands of the game overrides the need for excellent sprint technique. Previous researchers mention that the depth of information surrounding 'optimum technique' is lacking, and had difficulty identifying any biomechanical research detailing technique for optimising COD speed (Hewit et al., 2012; Hewit et al., 2013; Jones et al., 2017; Young et al., 2002). Some studies described the act of 'agility' and 'COD' with no accompanying technical models for improving these qualities (Hewit et al., 2011; Jones et al., 2017). There are also limited studies investigating training interventions based on select components of agility depicted in Table 2.1 (Young, 2006). One study found positive results on COD/agility using a training intervention focused on youth athletes, which can produce misleading conclusions about how to train this component of fitness when applying the findings to other populations (Watts, 2015). Another study with positive results used a basic strength program with the back squat as a main movement, for a period of two years with high school level soccer players (Keiner et al., 2014). Often any method of training, if consistent over extended periods of time, will result in improvements across numerous components of fitness when working with youth participants. Most of the literature recommends that use of external cues on body position and technique are effective to develop COD skills rather than the use of tools like speed ladders as a main focus for improving agility (Gleason et al., 2015; Hewit et al., 2011; Thomas et al., 2018). The effectiveness of which cues, body positions, training methodology and loading parameters for deceleration and COD for specific sports are still relatively unclear from this literature search and warrant further investigation (Hewit et al., 2013).

When changing direction the athlete is required to rapidly and systematically coordinate force and impulse application during the breaking phase (eccentric/deceleration), the plant phase (isometric/dynamic balance), and propulsive phase (concentric/acceleration) of the movement task (Dawes & Roozen, 2012; Hewit et al., 2011; Hewit et al., 2012; Jones et al., 2017; Thomas et al., 2018). Hewit et al. (2011) describe the desirable characteristics of the deceleration skill (Table 2.3). This compares the kinematic differences in relation to ground contact between acceleration and deceleration movement strategies. To accelerate, the body is in a forward lean position and to decelerate, the opposite position is required, with a backward lean is adopted to apply breaking forces in front of the body's COM at the point of first ground contact at heel strike (Hewit et al., 2011; Young, 2006). The breaking phase is maximised to eliminate the propulsive phase which is seen through increasing ground contact times (Hewit et al., 2011). The second breaking force is seen with hip and knee flexion, and ankle dorsiflexion to absorb the ground force across as many joints as possible (Hewit et al., 2011; Tominaga et al., 2016). During this time, preactivation of the quadriceps and gastrocnemius occurs to protect joints and further dissipate force across the lower body through muscle and connective tissue (Hewit et al., 2011). While decelerating step widths are wide to improve stability and base of support, two feet are often in contact with the ground surface simultaneously to dissipate higher forces across more joints (Hewit et al., 2011).

Table 2.3 Kinematic differences between the ground contacts of the acceleration and deceleration phases of sprinting (Hewit et al., 2011)

Kinematic Characteristic	Acceleration Phase (0-10m)	Deceleration Phase (0-5m)
Centre of mass in relation to point of contact	Anterior	Posterior
Step length	Short	Short
Step width	Wide	Wide
Step frequency	High	High
Breaking phase	Minimised/eliminated	Maximised
Propulsive phase	Maximised	Minimised/eliminated
Joint stiffness	Increased	Decreased
Support phase	Lengthened	Lengthened
Landing distance	Minimised	Maximised
Ground contact time	Long	Long
Predominant muscle action through support phase	Concentric	Eccentric
Flight phase	Minimised	Minimised/eliminated

These movement strategies are important for injury prevention/rehabilitation to identify risky movement strategies (Dawes & Roozen, 2012; Hewit et al., 2011). The more breaking force dissipated across as many joints as possible, the more rapid the ability to decelerate (Dawes & Roozen, 2012; Dos'Santos, Thomas, Comfort, et al., 2018; Hewit et al., 2011). Arm action is reduced and brought in closer to the COM to quickly initiate torso rotation and lead the body in its intended direction post deceleration (Dawes & Roozen, 2012; Hewit et al., 2011; Hewit et al., 2012; Hewit et al., 2013). The torso should remain upright and close to the athletes COM with shoulders behind point of contact with ground surface to allow for greater stability to prepare for rapid repositioning of limbs for the subsequent COD (Dawes & Roozen, 2012; Hewit et al., 2011; Hewit et al., 2012; Hewit et al., 2013). These kinematic observations of the deceleration phase are useful starting points for instructing movement strategies (Hewit et al., 2011; Hewit et al., 2012; Hewit et al., 2013). The eccentric capacity of the athlete needs to be high enough to tolerate the required force to eliminate an individuals own specific propulsion/momentum with reference to the required angle of COD (Baker & Newton, 2008; Dawes & Roozen, 2012; Dos'Santos, Thomas, Comfort, et al., 2018; Hewit et al., 2011).

The most common cutting technique seen in the rugby codes is the sidestep (Green et al., 2011). To move to the right a player will plant the left leg to decelerate and push off onto the right leg to continue in the intended direction (Green et al., 2011; Young, 2006). This differs to the crossover cut seen in American football where to move to the right the athlete will plant the right leg to decelerate and push off as the left leg swings across to accelerate to the right (Green et al., 2011). The rugby player will maintain a lower posture and COM and use a higher step frequency than the tall upright posture and elongated strides seen in maximum velocity sprinting (Young, 2006).

Shimokochi et al. (2013) suggested that body COM lateral velocity and foot contact time for decelerating and accelerating body COM should be assessed to understand specific lateral cutting competency. The ability to quickly change direction of momentum and body COM is essential for superior sport performance (Graham-Smith et al., 2018; Harper et al., 2018; Jones et al., 2017; Shimokochi et al., 2013; Smith et al., 2009). Lateral cutting index is calculated by dividing the lateral velocity of the body COM at take-off by the foot contact time (Shimokochi et al., 2013). The lateral cutting index reflects how fast subjects stopped momentum completely and reapplied force in the desired direction to gain momentum again (Shimokochi et al., 2013). Lowering the body COM by flexing the lower extremity joints is typically considered important to change direction quickly (Graham-Smith et al., 2018; Harper et al., 2018; Jones et al., 2017; Shimokochi et al., 2013). One study used motion analysis and force plates to collect information about the cutting movement subsequent to two sliding steps with basketball players (Shimokochi et al., 2013). The speed at which participants entered the force plate was not a controlled velocity from what can be understood in methods of this study, this is a variable of interest as it will likely affect the kinetics and kinematics of the lower body to complete the task and differ between participants. Results of this study indicated that hip extension maximum velocity was significantly related to greater lateral cutting index, as well as hip extension velocity at foot contact (Shimokochi et al., 2013). However hip abduction velocity at foot contact and hip abduction maximum velocity did not show a significant relationship with superior lateral cutting (Shimokochi et al., 2013). This shows the importance of hip extension to powerfully extend the hip at foot contact for superior performance in lateral cutting (Shimokochi et al., 2013). The abduction findings reflect that the movement relies on adduction rather than abduction to execute the movement. Greater GRF and smaller GRF angle were significantly associated with greater lateral cutting index (Shimokochi et al., 2013). A lower COM during lateral cutting was associated with higher lateral cutting index (Shimokochi et al., 2013). The amount of horizontal GRF during foot contact in the lateral cut was seen to be directly related to the velocity of the body COM at foot contact (Shimokochi et al., 2013). Flexing lower extremities to lower COM and utilising a wide stance is seen to be superior movement strategy to control the body at increasing velocities (Graham-Smith et al., 2018; Harper et al., 2018; Jones et al., 2017; Shimokochi et al., 2013). A visual assessment suggested by Shimokochi et al. (2013) is to ensure that the angle of movement (GRF vector) runs through the COM.

To avoid injury it is recommended that coaches spend more time with developmental athletes on movement specific skills, rather than advancing through progressions that are too complex (Gleason et al., 2015). Some coordination benefits may occur for beginners through the use of modes such as agility ladders (Gleason et al., 2015). However, improving agility for advanced athletes will require sport specific drills. Sport specific agility performance improvement may be best developed through the use of small sided games, evasion drills and sport skills practice (Gleason et al., 2015). It is highly recommended that sport coaches consult the deterministic model of agility and sport specific skill acquisition related to the skill development tools used in training (Table 2.1). This will allow the coach to avoid the use of tools that have questionable transfer to sport performance (Gleason et al., 2015). Coaches should avoid excessive volumes of training beyond those that are shown to further enhance sport skills or beyond the scope of the training intentions (Gleason et al., 2015). Excessive volumes can produce fatigue that may reduce the overall quality of the training session, residual fatigue that may reduce the quality of successive training sessions and potentially may lead to overuse or fatigue related injury (Gleason et al., 2015).

Lockie et al. (2013) observed that the enforced stop zone used in their study caused increased knee flexion torque on the front breaking leg after the 40m sprint, placing great eccentric stress on the hamstring. This is in agreement with scientific theory that adaptations occur in relation to the eccentric loading during a deceleration or breaking movement (Delaney et al., 2016; Dos'Santos, Thomas, Comfort, et al., 2018; Jalilvand, Banoocy, Rumpf, & Lockie, 2018; Lockie et al., 2015; Lockie et al., 2013; Taber et al., 2016; Thomas et al., 2018). Improving efficacy of knee movement strategies to absorb breaking forces after high velocity movement is an important area to focus on (Lockie et al., 2013; Taber et al., 2016). Lockie et al. (2013) also demonstrated increased between leg strength even though the participants were instructed to alternate front legs at the stop. Favouring one leg over another during COD/agility is not unusual, however, an effort to control strength imbalances between legs should be made to prevent injury and increase versatility (Hart et al., 2014; Lockie et al., 2013). The dominance of one limb for deceleration may also be related to the natural superior leg for acceleration (Lockie et al., 2013). For example, the athlete may stop with the right leg in front because the right leg can push off more powerfully once they have executed a COD. This may relate to the effective utilisation of the SSC of a dominant leg. It is important to reduce asymmetries with deceleration and acceleration strength strategies to be able to slow down effectively and still push off effectively with a non-dominant leg (Gleason et al., 2015; Lockie et al., 2013). Athletes need to be prepared to exert high forces through the less favourable leg without getting injured to be a robust and diverse athlete (Gleason et al., 2015; Lockie et al., 2013). Similarly, over using the strong leg and increasing the asymmetries further increases potential for overuse injury in the dominant leg, and increasing risk of the non-dominant leg by not being prepared for the unpredictable demands of the game (Gleason et al., 2015; Lockie et al., 2013).

Strength

Strength is one of the identified muscle qualities needed for effective deceleration, COD and agility performance (Baker & Newton, 2008; Bourgeois et al., 2017; Dawes & Roozen, 2012; Kovacs et al., 2008; Young, 2006). However, it should not be expected to produce outcomes of improved agility performance when used in isolation as the sole training method to address this performance need (Baker & Newton, 2008; Delaney et al., 2016; Spiteri et al., 2015; Young, 2006). Watts (2015) concluded that maximal and relative strength play a significant role in superior COD. Some form of strength training should be implemented to improve COD ability (Gleason et al., 2015). Athletes must possess adequate eccentric, concentric, isometric and dynamic strength to execute rapid COD. Improvements in these strength capacities subsequently increase the amount of force and impulse production during the movement, increasing performance further (Bourgeois et al., 2017; Hart et al., 2014; Sheppard et al., 2014; Spiteri et al., 2015). Muscular contribution during COD tasks has been seen to increase with increasing numbers of turns and changes in turn angles (Spiteri et al., 2015). Possessing adequate strength for the demands of the task is important for performance as well as injury prevention (Spiteri et al., 2015).

Deceleration is an eccentric motion, during muscle lengthening and repositioning of limbs to apply breaking forces, elastic energy is being stored (Baker & Newton, 2008; Dawes & Roozen, 2012; Joyce & Lewindon, 2014). The ability to decelerate rapidly and apply greater breaking forces will enable stored energy to be quickly utilised for re-acceleration (Dos'Santos, Thomas, Comfort, et al., 2018; Hewit et al., 2011; Jones et al., 2017). The longer it takes the athlete to slow down and the more steps taken to stop (i.e. high number of softer steps to break) the less efficient the athlete (Baker & Newton, 2008; Dawes & Roozen, 2012; Dos'Santos, Thomas, Comfort, et al., 2018; Jones et al., 2017; Joyce & Lewindon, 2014). Weaker athletes may need to take more steps to stop than stronger athletes traveling at the same velocity with the same body mass. The eccentric capacity of the athlete needs to be high enough to tolerate the required force to eliminate an individuals own specific propulsion/momentum with reference to the required angle of COD (Bourgeois et al., 2017; Dos'Santos, Thomas, Comfort, et al., 2018; Hewit et al., 2011; Hewit et al., 2012; Jones et al., 2017; Taber et al., 2016). The time an athlete takes to decelerate over a given distance is crucial for superior performance (Baker & Newton, 2008; Dawes & Roozen, 2012; Dos'Santos, Thomas, Comfort, et al., 2018; Jones et al., 2017; Joyce & Lewindon, 2014). Being able to decelerate in very few steps with the intent to execute a COD, jump or brace for impact is vital (Jones et al., 2017; Taber et al., 2016). Stopping a body in motion requires more opposing strength than what is in motion to stop the momentum, this requires high levels of eccentric strength during the deceleration phase, especially when needing to do so rapidly, from high speeds (Baker & Newton, 2008; Bourgeois et al., 2017; Dawes & Roozen, 2012; Dos'Santos, Thomas, Comfort, et al., 2018; Hewit et al., 2011; Jones et al., 2017; Joyce & Lewindon, 2014).

Eccentric strength training typically involves training muscle groups through the lengthening phase of a movement and this should be done both bilaterally and unilaterally (Bourgeois et al., 2017; Dos'Santos, Thomas, Jones, & Comfort, 2018; Harper et al., 2018; Kovacs et al., 2008; Young et al., 2002). Kovacs et al. (2008) stated that trained individuals should be able to support approximately 30% more weight eccentrically than concentrically. Insufficient eccentric strength may make muscle and joint structures more vulnerable to injury (Dos'Santos, Thomas, Comfort, et al., 2018; Kovacs et al., 2008). After a single bout of eccentric exercise cytoskeletal proteins including desmin and titin are disrupted, and degradation occurs up to 30% (Kovacs et al., 2008). This encourages protective adaptation to occur to be able to protect cytoskeletal proteins against future damage and lengthening, this is especially important in the context of rapid unplanned deceleration (Kovacs et al., 2008). It is important to train at a wide range of angles with eccentric exercises as muscle fibre architecture (shape, length, insertion location and orientation) differ within and between muscle groups (Baker & Newton, 2008; Dalen et al., 2016; Delaney et al., 2016; Griffith, 2005; Harper et al., 2018; Hart et al., 2014; Jones et al., 2017; Kovacs et al., 2008). This provides opportunity for more muscle fibres to adapt and shift the length-tension relationship to prevent injury (Kovacs et al., 2008).

The neural control required during eccentric contraction is different to that of concentric contractions, different motor units, levels of muscle activation and afferent feedback systems are used for each of these contraction types (Baker & Newton, 2008; Kovacs et al., 2008). Specificity of contraction type during training is extremely important, a coach cannot expect an athlete to be strong during eccentric contractions by prescribing primarily concentric movements (Baker & Newton, 2008; Kovacs et al., 2008). The posterior muscles of the lower body (hip extensors, glutes, hamstrings) should be a focus for training (Kovacs et al., 2008). This should be done in an eccentric manner to benefit deceleration ability and to protect against injury during deceleration and unplanned changes of direction (Baker & Newton, 2008; Bourgeois et al., 2017; Dalen et al., 2016; Delaney et al., 2016; Harper et al., 2018; Jalilvand et al., 2018; Jones et al., 2017; Kovacs et al., 2008). This needs to be monitored closely as there are limited guidelines on deceleration training available. Practitioners need be aware that eccentric training causes more delayed onset muscle soreness, even though it is not necessary to generate damage to a great extent to elicit the desired training adaptations (Kovacs et al., 2008). Brughelli and Cronin (2007) suggested that high intensity, high volume and eccentric exercise performed at longer lengths result in greater shifts in optimum length. With regard to the length-tension relationship, a sustained shift in optimum length may be achieved after only four weeks of implementing eccentric training (Brughelli & Cronin, 2007). Eccentric training has also been shown to have positive effects on side stepping ability with rugby players (Hewit et al., 2012).

Hart et al. (2014) and Sheppard et al. (2014) concluded that there are relationships between eccentric, concentric and isometric strength and COD performance. Therefore, developing greater capacities across these types of strength will benefit performance (Baker & Newton, 2008; Delaney et al., 2016; Harper et al., 2018; Jalilvand et al., 2018; Spiteri et al., 2015; Taber et al., 2016). All strength qualities are used during COD and agility tasks and should all be focused on during training (Baker & Newton, 2008; Dalen et al., 2016; Delaney et al., 2016; Dos'Santos, Thomas, Jones, et al., 2018; Gabbett et al., 2008; Harper et al., 2018; Hewit et al., 2013; Jalilvand et al., 2018; Spiteri et al., 2015; Taber et al., 2016; Watts, 2015). It is important to be able to apply greater force and impulse while being able to control the body to execute a COD to produce a faster performance (Spiteri et al., 2015). Spiteri et al. (2015) showed that the 505 COD test had higher eccentric loading and breaking force demands, and need for higher propulsive forces to produce a superior performance than the requirements of the T-Test. It is valuable to improve all strength capacities to improve performance across both tests (Spiteri et al., 2015).

Watts (2015) concluded that improving maximal relative strength in a vertical direction should be a primary focus in any program designed to improve COD speed. This conclusion was based on the Green, Blake and Caulfield (2011) study exploring hip extension velocity in rugby union starter verses non-starter COD performance. Watts (2015) suggested that hip extension in COD patterns is purely vertical force application, this finding could be debated, and direction of hip extension instead interpreted as horizontal force application in this COD context. In this study the strength group used front and back squat variations, which resulted in higher COD performance than the control group which only performed COD skill based sessions and no strength training (Keiner et al., 2014; Watts, 2015). An obvious difference in performance with the strength trained group was attributed to improved strength in similar planes to what is required to apply breaking forces (Keiner et al., 2014; Watts, 2015). That is weight in the heels and improved eccentric and concentric muscle action to improve tolerance to decelerate and store elastic energy and utilise this in the subsequent movement. Strength training the gluteal muscles will usually improve performance in acceleration as these are the prime movers during these movements (Contreras, Vigotsky, Schoenfeld, Beardsley, & Cronin, 2015). During COD tasks the acceleration and deceleration motions are positive and negative horizontal movements (Hewit et al., 2011). The improvements from squatting are applied in a horizontal direction, which suggests an exercise like a barbell hip thrust would be even more specific as it has a higher gluteal muscle activation seen in EMG studies compared to a squat (Contreras et al., 2015). This author's conclusions do not explain the intricacies of horizontal and vertical force production in acceleration and COD contexts. Other research has reported single leg horizontal strength as highly correlated to COD performance (Hewit et al., 2012; Jones et al., 2017). Maximally strength training the glutes and hamstrings using most exercises, (vertically or horizontally, isometrically and eccentrically) could be better recommendations to make for strength training for improving COD and deceleration performance. Side stepping ability has been strongly influenced by eccentric strength training, reducing the time to decelerate momentum in a shorter distance (Harper et al., 2018; Hewit et al., 2012; Jones et al., 2017). Also, the age and potential lack of training history of the participants used in this study may not be appropriate to make a general conclusion as the participants used would have improved from any number of strength exercises in a similar way (Keiner et al., 2014; Watts, 2015).

Reactive Strength and Dynamic Balance

Reactive strength is another component of deceleration, and is described as the ability to quickly change from an eccentric to a concentric muscle contraction, enhanced by effective utilisation of the SSC muscle contraction sequence (Baker & Newton, 2008; Hewit et al., 2011; Kovacs et al., 2008; Taber et al., 2016; Young, 2006; Young et al., 2002). Effective utilisation of the SSC is a very specific form of muscle power (Kovacs et al., 2008; Young, 2006; Young et al., 2002). Although the athlete comes to a stop, energy is not lost during the deceleration phase when approaching a COD (Hewit et al., 2011). Elastic energy is stored during the eccentric muscle action, this energy is then utilised to change direction, accelerate, jump or any other movement to follow (Baker & Newton, 2008; Hewit et al., 2011; Taber et al., 2016; Young et al., 2002). Optimising this could require being as 'stiff' as the body can tolerate during the eccentric phase while applying breaking forces, to then effectively transmit the stored energy during the following concentric muscle action (Hewit et al., 2011). Although the joint stiffness is reduced during the deceleration phase to absorb force, when reapplying force, stiffness needs to be maximised to transfer the stored elastic energy rapidly through the tendons and connective tissues of the muscle (Hewit et al., 2011).

Most plyometric exercises are geared towards the development of power and creating more stable movement pathways with jump and landing mechanics (Joyce & Lewindon, 2014; Kovacs et al., 2008). Neuromuscular adaptations occur to the stretch reflex, the elastic properties of muscle and to the Golgi tendon organ become desensitised to allow the body to stretch or load beyond previous capacities (Kovacs et al., 2008). Desensitisation of this protective mechanism allows the elastic component of the muscle to lengthen further and therefore generate more elastic energy for the subsequent expression of force, resulting in a more powerful concentric contraction (Joyce & Lewindon, 2014; Kovacs et al., 2008). Kovacs et al. (2008) suggested that plyometric movements help train the ability to absorb breaking forces, which is important for improving deceleration skill and reactive strength. Plyometric training has also been recommended as an effective method of increasing COD performance due to the similar force and power outputs, SSC utilisation and ground contact time, crucial for superior COD performance and injury prevention (Dos'Santos, Thomas, Comfort, et al., 2018; Joyce & Lewindon, 2014). Greater vertical breaking and propulsive force and impulse have been identified as components that result in faster exit velocities from a 45 degree turn during a COD task (Spiteri et al., 2015). Different kinetic and kinematics will be required for superior performances in varying angles and number of turns to be executed during a given task (Dawes & Roozen, 2012; Spiteri et al., 2015).

Energy leakage is a term describing energy being directed in ways other than the intended direction of movement (Joyce & Lewindon, 2014). An example of energy leakage is valgus or varus collapse of the knee, whereby energy is wasted laterally as the knee softens and re-stiffens (Joyce & Lewindon, 2014). This can be related to dynamic balance, or dynamic isometric strength, which is the preparedness of the tendons to tolerate and transfer force, while maintaining effective joint integrity and COM through motion (Joyce & Lewindon, 2014). If the knee was secure, energy would be more effectively used in the intended direction of motion.

Athletes cannot afford to waste the elastic energy generated during eccentric muscle action, especially when needing to change direction rapidly in a game scenario to react and break a line or make or avoid contact with an opposition (Joyce & Lewindon, 2014; Thomas et al., 2018). Stronger athletes often have better ability to utilise the SSC and stored elastic energy (Hewit et al., 2011; Joyce & Lewindon, 2014). Longer contacts with the ground rather than many quick contacts to slow down are a better strategy to decelerate and optimise the storage and transfer of elastic energy (Hewit et al., 2011). It is expected that programs using jumping exercises with single leg take-offs and landing like bounding may have more transfer to improving COD speed than just relying on pure strength training (Young, 2006). As expected, vertical jumping also has high positive correlations to COD speed, due to the similar SSC requirements and hip, knee and ankle flexion and extension movement patterns (Lockie et al., 2018).

Dynamic balance is another major influence on deceleration performance and is defined as the ability to maintain a stable of centre of gravity through motion (Kovacs et al., 2008). Optimally utilising the segmental summation of muscular forces to efficiently transfer energy through the entire kinetic chain will produce a more powerful movement (Joyce & Lewindon, 2014; Kovacs et al., 2008). Improved dynamic balance results in improved body control while decelerating (Joyce & Lewindon, 2014; Kovacs et al., 2008). This ability to utilise muscle groups optimally without sacrificing movement strategies will allow for more forceful COD, tackles or evasions (Joyce & Lewindon, 2014; Kovacs et al., 2008; Thomas et al., 2018). Changes in sensory systems and motor systems can influence balance performance (Joyce & Lewindon, 2014; Kovacs et al., 2008). Plyometric exercise encompasses a number of reflexive pathways that can produce neural muscular and joint adaptations to prepare the body for unplanned movements while remaining in control of the body (Joyce & Lewindon, 2014; Kovacs et al., 2008). The feedback produced in plyometric exercises will create protective adaptations in preparation for unplanned changes of direction that may reduce risk of injury and maintain a stable COM (Joyce & Lewindon, 2014; Kovacs et al., 2008).

Sprint Speed

Superior sprint speed is important on the field, but does not always translate to superior performance with agility and COD tasks (Baker & Newton, 2008; Dawes & Roozen, 2012; Holmberg, 2009; Joyce & Lewindon, 2014; Sheppard et al., 2014; Sheppard & Young, 2006; Young, 2006; Young et al., 2002). However, sprint speed and body mass have been reported as strong indicators of COD performance (Baker & Newton, 2008; Delaney et al., 2016). As such, a determining factor on the ability to decelerate is the concept of momentum, which is the mass of the athlete and the velocity at which they are traveling (Baker & Newton, 2008; Hamilton, Weimar, & Luttgens, 2012). As an athlete gains more mass or increases velocity their momentum is amplified, requiring deceleration ability to improve accordingly as either of these factors increase (Baker & Newton, 2008; Hamilton et al., 2012; Hewit et al., 2013; Kovacs et al., 2008; Watts, 2015). An athlete who cannot control their momentum to decelerate effectively will be less competitive or become susceptible to injury (Baker & Newton, 2008; Dawes & Roozen, 2012; Hewit et al., 2013; Kovacs et al., 2008). Similarly, the power to mass ratio exhibited by an individual is also highly important during sprint and COD tasks (Baker & Newton, 2008; Delaney et al., 2016). Once a desired body mass has been reached, the ability to apply more force per unit of body mass is a determining factor of superior performance in deceleration, acceleration and COD tasks (Baker & Newton, 2008; Delaney et al., 2016).

As mentioned, research suggests that straight sprint speed does not always correlate to superior COD performance (Baker & Newton, 2008; Holmberg, 2009; Joyce & Lewindon, 2014; Sheppard et al., 2014; Sheppard & Young, 2006; Young, 2006; Young et al., 2002). Slower athletes or athletes with less mass have less momentum to stop, making them appear to be superior at agility (Baker & Newton, 2008; Delaney et al., 2016; Nimphius et al., 2018; Nimphius et al., 2016). It is also important to note that COD tests that have a high volume of linear sprinting can provide false results, where athletes can offset poorer COD ability with superior sprint ability (Nimphius et al., 2018; Nimphius et al., 2016). Alternatively, athletes may reduce speed in anticipation for demanding COD to reduce breaking force requirements and remain in control, making up time during the re-acceleration component of the COD (Nimphius et al., 2018; Nimphius et al., 2016). In the context of sport these athletes may be less effective on the field as they are slower and weaker than the faster athletes or those possessing more functional mass or a higher power to mass ratio (Delaney et al., 2016).

Team sport athletes who are superior sprinters should incorporate deceleration training to improve their ability to break and control the body during changes of direction. This is especially true for athletes in programs that emphasise improving sprint speed, but neglect deceleration ability. If it is the case that deceleration can be trained effectively it should be looked at the way we isolate acceleration as an explicit component to improve (Lakomy & Haydon, 2004). COD skills and drills need to emphasise the importance of being able to accelerate and decelerate and re-accelerate rapidly in different directions repeatedly (Hewit et al., 2013; Sheppard et al., 2014).

Ground Reaction Force

Tominaga, Ishii, Ueda and Kurokawa (2016) investigated the effect running speed has on GRF during deceleration and lower limb kinematics when adopting a single leg stop movement strategy. The main finding was that as running speed increases so does the magnitude of GRF, therefore adjustments in hip and ankle flexion angle strategies are required to accommodate absorbing higher GRF to decelerate as a result (Tominaga et al., 2016). Rapid stops and changes in direction from different running speeds are important components of team sports (Joyce & Lewindon, 2014; Tominaga et al., 2016). GRF peaks while decelerating from different running approach speeds were investigated (2.5m/s, 2.75m/s, and 3m/s) (Tominaga et al., 2016). Approach speeds were limited by the ability of the participants, therefore the trend of increased adjustments seen at the lower speeds in this study would be amplified at increasing speed (Tominaga et al., 2016). From this GRF analysis, during deceleration peak one was seen at heel strike, where the soleus muscle becomes active in preparation for heel strike, which occurred earlier as running speed increases (Tominaga et al., 2016). Speed of hip flexion and ankle dorsiflexion increased as running speed increased (Tominaga et al., 2016). It was suggested that adjustments in knee flexion at heel strike could be expected at higher running velocities than used in this study (Tominaga et al., 2016).

Similarly, Harper, Jordan and Kiely (2018) investigated the role of knee extensors and flexors during rapid linear deceleration tasks. This study had used approach velocities prior to rapid deceleration that were higher than previous studies, therefore being closer to on field performance (Harper et al., 2018). Breaking force requirements and associated mechanical demands increase as speed increases, specifically increasing load on the knee extensors to decelerate (Harper et al., 2018; Hewit et al., 2012; Hewit et al., 2013; Jones et al., 2017; Tominaga et al., 2016). Knee extensor and knee flexor strength plays an important role in the ability to decelerate in a shorter time or distance (Harper et al., 2018; Jones et al., 2017). It was recommended by Harper, Jordan and Kiely (2018) that utilising velocity-based strength training for movements specific to deceleration, which focus on knee flexion and extension will improve deceleration ability and prevent common COD injury.

Repeat Deceleration Fatigue

Muscle activation and contraction speed of the knee extensors and flexors begin to reduce or delay under fatigue, and maximum knee flexion angle occurs earlier while under fatigue when performing a rapid stop (Nyland, Shapiro, Stine, Horn, & Ireland, 1994). Under fatigue, knee strategies to stop, land and control the body during deceleration and execution of COD tasks are modified with reduced muscle activation occurring to protect joint structures (Joyce & Lewindon, 2014; Nimphius, 2014; Nyland et al., 1994; Tominaga et al., 2016). Tominaga et al. (2016) have found limited explanation around technique and stopping strategies when needing to control the body at higher velocities and high volume with their literature search (Baker & Newton, 2008; Gabbett et al., 2008; Gleason et al., 2015; Hewit et al., 2011; Hewit et al., 2012; Hewit et al., 2013; Nimphius, 2014; Sheppard et al., 2014; Sheppard & Young, 2006; Spiteri et al., 2015). This is more reason to investigate deceleration and fatigue to understand injury risk, movement strategies and how to create a robust athlete.

Lakomy and Haydon (2004) investigated the effect of incorporating a deceleration zone in a repeat sprint ability test. Repeat speed ability is important in almost all team sports (Joyce & Lewindon, 2014). However some tests used to assess COD performance measures do not effectively assess repeat deceleration subsequent to repeat maximal sprints. The Yo-Yo2 could be an appropriate test in this area of performance measurement as it involves repeated COD, however athletes may not always reach the velocities that they are ordinarily capable of in repeat speed tests if they are not proficient at COD or have poor aerobic fitness. If repeat deceleration is a significant reason for not being able to achieve higher levels in performance testing due to increased fatigue, athletes may be set up to fail by choosing an inappropriate test. Lakomy and Haydon (2004) used a modified repeat speed test similar to the Phosphate Decrement Test (PDT). This consisted of six efforts of 40m with a 30 second turn around between efforts whereas the traditional PDT uses ten sprint repetitions. The modified test incorporated a 6 metre deceleration zone where the athletes in the experimental group had to come to a stop within from their 40m maximal sprint (Lakomy & Haydon, 2004). The control group could decelerate at their leisure within the 30 second turn around before the next effort (Lakomy & Haydon, 2004). The PDT or other repeat speed tests are good for testing the ability to recover between maximal effort sprints by looking at the percentage drop off per sprint through the test. However, they cannot predict true on field performance of repeat sprinting as on field sprinting will often be in reaction to a stimulus requiring rapid deceleration immediately after the stimuli is recognised (Gleason et al., 2015; Holmberg, 2009). Sprint durations and volume during rugby games have been quantified using global positioning system (GPS), using this data can be problematic due to the categorisation of efforts and loading during short distance high velocity acceleration and rapid deceleration often being miscategorised as low intensity work (Dalen et al., 2016; Ross, Gill, Cronin, & Malcata, 2015). The eccentric nature of deceleration will influence fatigue which is not appropriately measured in most testing procedures. As eccentric loading causes more muscle damage than concentric movements, the effect of this on in-game fatigue or recovery ability is valuable to investigate in depth (Lakomy & Haydon, 2004). There could be value in developing a specific repeat rapid deceleration performance measure. A combination of the short maximal sprint distances and intermittent shuttle style of the Yo-Yo and modified PDT could be used to assess repeat deceleration recovery.

Athletes who do not have adequate skill in decelerating may be fit and fast enough to reach the higher levels of performance in specific tests used like the Yo-Yo1 and Yo-Yo2 but may not produce good scores. They may have trouble controlling momentum to effectively slow down rapidly while maintaining intensity (Dos'Santos, Thomas, Comfort, et al., 2018). This could be that they are faster, more powerful athletes, therefore it takes more energy to slow their momentum than a lighter and slower athlete (Dos'Santos, Thomas, Comfort, et al., 2018). Additionally, they may have more muscle mass, increasing momentum further, as well as having more muscle fibres or area for eccentric muscle damage and fatigue to occur, limiting performance yet again. The faster, more muscular athletes must be able to tolerate higher levels of eccentric loading and subsequent fatigue to achieve the same score as a slower or lighter athlete. This calls into question the appropriateness of certain testing methods to differentiate between superior and inferior athletes. Examples of this may be seen in using the protocol of Lakomy and Haydon (2004). If they had decided to compare fast sprinters with slow sprinters with an enforced deceleration zone the differences in fatigue between the different standards of sprint ability would have been interesting. Investigating this protocol would be beneficial as the impact of rapid deceleration on fatigue is not well documented, but it was hypothesised that rapid deceleration exacerbates fatigue due to eccentric loading required to apply breaking forces (Lakomy & Haydon, 2004).

An in depth study on repeat deceleration fatigue was presented by Lakomy and Haydon (2004). It was expected that the deceleration condition would induce significantly higher fatigue, measured by a fatigue index based on the percentage of drop off in time per sprint (Lakomy & Haydon, 2004). As the protocol was only a 6x40m repeat sprint on 30sec turn around, there was no significant difference between the fatigue observed in each group (Lakomy & Haydon, 2004). Based on the data, they found that if the protocol included a greater number of sprints, differences in fatigue would reach statistical significance at the 11th sprint (Lakomy & Haydon, 2004). If they had used the traditional repetitions for the PDT their results could have been stronger to understand the occurrence of deceleration fatigue with repeated maximal sprints (Lakomy & Haydon, 2004). It was also acknowledged that the subjects used were already highly trained in the eccentric muscle action of rapid stopping, and that the significance that was expected could not be present in only six repeat sprints (Lakomy & Haydon, 2004). This again could be applied to an elite versus senior or development level player investigation, where it could be expected that elite athletes in rugby sevens may have a higher tolerance or ability to perform repeat sprints with a deceleration zone than a lower level player. This could be investigated further to develop a deceleration zone guideline following maximum sprints, or looking at the different strategies superior decelerators use compared to inferior decelerators. Repeat speed ability suffers when being required to decelerate rapidly and repeatedly, this is an important aspect of team sport game play and competitive advantage (Joyce & Lewindon, 2014; Lakomy & Haydon, 2004).

During professional soccer games it was shown that the ability to maintain high intensity acceleration and deceleration efforts was reduced significantly in the last 15 minutes of match play (Russell et al., 2016). Russell et al. (2016) suggested that the more a player is required to accelerate and decelerate from high intensity, the higher the energetic cost required to tolerate these demanding loads. A large amount of rapid decelerations will have a significant effect on fatigue and energy expenditure for specific individuals as the match progresses, particularly for faster players (Russell et al., 2016). The inability to tolerate this work load will reduce competitiveness near the end of a match, which could be crucial for the outcome of a game. In soccer, through the use of accelerometer data it has been reported that the number of decelerations per match contributed to 5-7% of the total player load (Dalen et al., 2016). Interestingly acceleration load was similar totalling 7-10% (Dalen et al., 2016). Assessing player loading through GPS is often highly underestimated due to the short distances covered that highly demanding efforts are occurring at, being categorised as low speed bouts, this would be better understood through the use of accelerometers (Dalen et al., 2016). It was also found that per metre, player load during acceleration and deceleration was considerably higher than other movement categorisations (Dalen et al., 2016). Player loading from maximal deceleration was reported to be much higher than acceleration, with a significantly higher energy cost for maximal deceleration compared to maximal acceleration (Dalen et al., 2016). Both Russell et al. (2016) and Dalen et al. (2016) suggested that there should be a large focus in training plans to increase the ability to repeatedly decelerate from high velocity sprinting to improve player performance.

Testing Change of Direction and Agility

As mentioned previously, COD tests used by sports do not always reflect the movements adopted during games (Barber, Thomas, Jones, McMahon, & Comfort, 2016; Dawes & Roozen, 2012; Joyce & Lewindon, 2014; Nimphius et al., 2018; Sheppard & Young, 2006). When using these tests for recruitment, they may not always differentiate between skilled and unskilled players when it comes to executing COD or agility movements on the field (Barber et al., 2016; Dawes & Roozen, 2012; Joyce & Lewindon, 2014; Nimphius et al., 2018; Sheppard et al., 2014; Sheppard & Young, 2006). It is important to measure COD performance using movements that are commonly performed during game play (Barber et al., 2016; Dawes & Roozen, 2012; Joyce & Lewindon, 2014; Nimphius et al., 2018; Sheppard & Young, 2006; Spiteri et al., 2015). It is unwise to compare tests of different natures, as force and impulse requirements are different depending on the dominant strength characteristics and movement mechanics required to execute the task (Dawes & Roozen, 2012; Nimphius et al., 2018; Spiteri et al., 2015). Most COD test research focuses on the context of injury prevention through differences between limbs, or movement strategies during an isolated movement, or to assess performance using the total time taken to complete COD task (Nimphius et al., 2018). Using specific COD tests to assess performance should be supported by assessment of the qualities that underpin the ability to change direction effectively to provide a comprehensive assessment of the ability to execute a COD (Nimphius et al., 2018). The ability for COD performance to be concealed by other qualities that are important during the task brings into question the validity of each COD test commonly used (Nimphius et al., 2018; Nimphius et al., 2016).

Hart, Spiteri, Lockie, Nimphius and Newton (2014) conducted a study assessing the effectiveness of the AFL agility test at assessing athletes of differing leg dominance by starting/finishing the test from opposite sides. The normal set up was appropriate for 61% of players, however, 39% had a superior performance on the alternate version using the other leg (Hart et al., 2014). Traditionally the AFL agility test has more turns to the left than to the right so this disadvantages those who are more dominant to the right (Hart et al., 2014). As it stands the test does not assess between leg performance deficits (Hart et al., 2014). When the performance deficit between limbs is reduced, the athlete could be more dynamic when selecting movement strategies in relation to a stimuli, which would be appealing to recruiters (Hart et al., 2014). The larger the deficit between limbs the higher the risk of injury when having to rely on the non-dominant side (Dos'Santos, Thomas, Jones, et al., 2018; Hart et al., 2014). With the high velocity approach to the first turn, there is a greater eccentric load compared to the subsequent turns, this could potentially put athletes at unnecessary risk of injury by expecting them to perform well on their non-dominant leg (Hart et al., 2014). Collecting this information could aid in developing strength and conditioning programs, and also ensure that steps are in place to monitor athletes with large deficits and attempt to reduce this (Hart et al., 2014).

Although the 505 COD test had higher eccentric loading and breaking force demands, and need for higher propulsive forces to produce a superior performance than the requirements of the T-Test, it is valuable to improve all strength capacities to improve performance across both tests (Barber et al., 2016; Lockie et al., 2015; Nimphius et al., 2016; Spiteri et al., 2015). Having robust movement strategies that are automatic to execute COD tasks on the field will increase the ability to identify relevant stimuli sooner (Holmberg, 2009; Spiteri et al., 2015). This allows the athlete to decelerate and apply greater breaking forces sooner to prepare for a reactive movement and result in a faster reaction to the situation (Baker & Newton, 2008; Spiteri et al., 2015).

505 Change of Direction Test

The 505 COD test requires long contact times during breaking and propulsive phases to decelerate and re-accelerate effectively by allowing longer time to absorb and apply force (Barber et al., 2016; Dawes & Roozen, 2012; Lockie et al., 2015; Nimphius et al., 2016; Spiteri et al., 2015). Greater eccentric strength capacity to absorb force during deceleration allows for better utilisation of the SSC for improved re-acceleration (Dawes & Roozen, 2012; Jones et al., 2017; Spiteri et al., 2015). This reduces time to stop, transition and to redirect force in a propulsive manner in the intended direction (Baker & Newton, 2008; Dawes & Roozen, 2012; Jones et al., 2017; Spiteri et al., 2015). Faster athletes in the 505 COD test demonstrated greater isometric strength, vital during the breaking and propulsive phase, optimising triple extension and stability during the plant phase while executing COD (Dawes & Roozen, 2012; Jones et al., 2017; Spiteri et al., 2015).

Nimphius et al. (2016) proposed a 505 deficit assessment to support the traditional 505 test assessing time to complete the task. The proposed 505 deficit requires no extra specialised equipment or analysis, using maximal 10m time and 505 time, by measuring the difference in time taken for each test (Lockie et al., 2018; Nimphius et al., 2018; Nimphius et al., 2016). The greater the deficit, the poorer the ability to change direction, or the closer a 505 time to 10m time the greater the performance. This assessment provides valid insight when using this to monitor changes as a result of the training program (Nimphius et al., 2016). If the 10m sprint time improves, but the 505 deficit remains unchanged or becomes larger, it could be suggested that

COD ability has not improved or worsened despite total time improving as a result of increased speed (Lockie et al., 2018; Nimphius et al., 2018; Nimphius et al., 2016). When using total time to complete a COD task, the actual qualities that need to be improved or are contributing to the performance can be overlooked and misunderstood for exercise prescription as a result (Nimphius et al., 2018; Nimphius et al., 2016). Nimphius et al. (2018) also suggested that an even more appropriate measure of deceleration or COD ability would be measurement of an individual's entry and exit velocity of COM performing a COD from high sprinting velocity. Further to this, the inclusion of body mass or momentum could be insightful for understanding performance change in the 505 COD test (Baker & Newton, 2008; Jones et al., 2017).

T-Test

During the T-Test, the participant must reposition and control momentum in multiple directions using different movement types (Spiteri et al., 2015). Faster athletes in the T-Test demonstrated superior strength capacity (Spiteri et al., 2015). The only variable that was significantly greater for faster performers was isometric strength, which is important for the plant phase while changing direction and maintaining a lower stance in preparation for in-game movements (Spiteri et al., 2015). The lower athletic stance optimises the length-tension relationship of the muscles in the lower body to increase force output and force absorption (Spiteri et al., 2015). Shorter breaking, propulsive and contact times were demonstrated by faster athletes in the T-Test (Spiteri et al., 2015). Faster athletes also possessed lower body fat percentage allowing them to execute turns faster as a result of less non-functional mass contributing to momentum deceleration and re-acceleration (Spiteri et al., 2015). During the T-Test breaking forces were not significantly different between slower and faster athletes (Spiteri et al., 2015). The COD in the T-Test does not require as a rapid deceleration with the COD angle being 90°, faster athletes however did produce significantly greater propulsive impulse compared to slow performances (Spiteri et al., 2015). Rapid deceleration is not a crucial component required for the T-Test, the ability to maintain a low body position allowing the athlete to control and extend the hip to increase propulsive ability is the factor that sets apart superior performances (Spiteri et al., 2015).

Characteristics of Superior Decelerators

When comparing higher level athlete groups of the same sport, it is true that the superior groups possessed higher straight-line sprinting ability, maximal aerobic power, technical skills, COD skill and other lower body strength qualities (Baker & Newton, 2008; Dalen et al., 2016; Dawes & Roozen, 2012; Delaney et al., 2016; Gabbett et al., 2008; Green et al., 2011; Harper et al., 2018; Hewit et al., 2013; Jalilvand et al., 2018; Jones et al., 2017; Keiner et al., 2014; Sheppard et al., 2014; Thomas et al., 2018; Watts, 2015). More experienced and superior athletes perform better across specific tests because of experience with the skill, which confirms the importance of COD skill acquisition (Sheppard et al., 2014). This skill is developed by improving postural control through changes in body position, reducing unnecessary movements, and having control of directional forces (Dawes & Roozen, 2012; Joyce & Lewindon, 2014; Sheppard et al., 2014). Sheppard et al. (2014) suggested that developing sprint speed and COD speed should be a priority in development athletes to improve movement efficiency and effectiveness, utilising closed skill tasks early on and progressing as the athlete improves.

Limited studies have investigated deceleration as an explicit component of physical fitness (Green et al., 2011; Harper et al., 2018; Hewit et al., 2011; Kovacs et al., 2008; Lakomy & Haydon, 2004; Lockie et al., 2013; Russell et al., 2016). Lockie, Schultz, Callaghan and Jeffriess (2013) investigated a deceleration training intervention with enforced stopping and found some positive results with performance measures. The training intervention was for six weeks and compared a control group with the deceleration intervention group following agility and acceleration training (Lockie et al., 2013). Both groups did the same training plan, with the intervention group being required to adopt an enforced stopping protocol at the end of drills and linear sprints (Lockie et al., 2013). When linear drills and sprints were performed, a split leg stance similar to the standing sprint start or shallow lunge position with one leg forward for the stop was required, alternating the lead leg each drill repetition (Lockie et al., 2013). Drills that incorporated a lateral shuffle or a back pedal required a ¼ squat stance for the stop position, these postures were held for 2 seconds to ensure a complete stop of motion (Lockie et al., 2013). The distances allowed for the deceleration zone were 3m following a drill or sprint up to 20m, and 6m following a drill or sprint of 30-40m (Lockie et al., 2013). The decision on break zone distances of 3m and 6m was not explained, but it was acknowledged that there needs to be further research on appropriate break zone distances following maximal sprints at different distances (Lockie et al., 2013). It was found that the experimental group who performed enforced stopping, increased concentric knee extensor and knee flexor strength (Lockie et al., 2013). Interestingly, the between leg strength difference was increased. Participants were instructed to alternate lead legs for deceleration, intensity on the non-dominant leg may have been lacking with regard to matching the dominant leg, which may have been out of the researchers control. The findings of this study confirm the potential benefits from adopting a deceleration specific component in training for team sports, even by including this at the end of drills and sprints.

Green, Blake and Caulfield (2011) compared starters versus non-starters in a semi-professional rugby union team performing a sidestep cutting movement. The ability to perform COD tasks at higher velocities is characteristic of superior playing ability (Green et al., 2011). The nature of rugby union requires the players to be dynamic with running and cutting decisions to create open space, evade or defend oppositional play (Green et al., 2011). Superior COD movement strategies were observed by starters, this was characterised by shorter contact time of the plant leg and faster initiation of knee extension of the push off leg during cutting (Green et al., 2011). This could be attributed to faster utilisation of elastic energy stored from shorter contact time of the plant/stop leg, meaning that they are faster to initiate re-acceleration, and are able to stick the plant leg with the intent to redirect immediately (Jones et al., 2017). This may provide competitive advantage on the field with evasion and defensive play (Baker & Newton, 2008; Green et al., 2011; Jones et al., 2017). The non-starters required a longer period of time to decelerate knee flexion signifying that they were slower in this initial transition from flexion to extension resulting in a slower time to push off and accelerate (Green et al., 2011). This suggests that the non-starters may have poorer ability to absorb force or poorer eccentric strength to slow their own momentum (Baker & Newton, 2008; Jones et al., 2017).

When using the 505 COD test and the T-Test to determine groups of faster and slower female basketball athletes, faster athletes have been shown to be superior performers across a number of other measures (Spiteri et al., 2015). Faster athletes over the 505 COD test possessed greater vertical force, eccentric strength capacity during an eccentric squat and isometric strength capacity during an isometric mid-thigh pull than slower performers (Baker & Newton, 2008; Delaney et al., 2016; Dos'Santos, Thomas, Jones, et al., 2018; Harper et al., 2018; Spiteri et al., 2015). Faster athletes over the T-Test had significantly shorter ground contact times, greater propulsive impulse, greater isometric strength capacity during mid-thigh pull and greater relative lean mass than slower athletes (Spiteri et al., 2015). Differences between male and female COD performance were also observed. Males apply more force and impulse through COD tasks, resulting in a superior performance (Spiteri et al., 2015). Gender differences that could account for differences in the ability to direct GRF are lower body anthropometrics, body composition and strength characteristics (Baker & Newton, 2008; Spiteri et al., 2015). These differences could be evident when comparing different levels of athletes e.g. elite versus club level, and comparing differences between elite men versus elite women. The superiority of male COD ability suggests that the ability to effectively and efficiently utilise strength during COD and agility could be the determining factor in the superior performances observed (Spiteri et al., 2015).

Change of Direction and Deceleration Research in Rugby Codes

Identifying the differences between levels of play and gender allows strength and conditioning practitioners to develop training and skill programs to work towards the game demands of the ensuing level of play. This increases understanding of what players should be expected to be able to do at each level to provide insight into implementing training progressions (Clarke, Anson, & Pyne, 2016). For example, elite women's Rugby Sevens players have a higher total running volume, and higher number of and duration of 'high speed' runs (sprinting over 5m/s) compared to women's senior club level players, (Clarke et al., 2016). As seen across many other sporting codes, as the level of play increases, the physical demands increase, namely speed and consequent increases deceleration ability (Green et al., 2011; Spiteri et al., 2015; Young et al., 2002). Because women's sevens is a relatively new sport it attracts a wide range of players from different sporting backgrounds who possess different skills and experience with training. This explains the difference in style of game compared to the refined skill with COD of the men's sevens players (Clarke et al., 2016). Men are typically conditioned from having a greater training history, with years of being involved in a rugby code, whereas anecdotally women come from a broad range of sports and do not possess the same skill set as men (Clarke et al., 2016).

Players who are faster over 10m and 40m distances are more likely to make a higher number of line breaks, a greater number of effective tackles and beating a greater number of defenders in rugby sevens, union, league and Australian rules football (Baker & Newton, 2008; Clarke et al., 2016; Ross et al., 2015; Thomas et al., 2018). Elite men's players have more advantageous anthropometric qualities, i.e. less non-functional mass, as well as more favourable physical qualities such as strength, speed, endurance (Baker & Newton, 2008; Clarke et al., 2016). GPS data is useful for examining the demands of a true on field performance, however the rugby sevens tournament data analysed by Clarke et al. (2016) does not provide us with insight into what has occurred following the running bouts described. It would be extremely useful to understand what velocity a player enters a collision or COD to be able to prescribe deceleration from game matched velocities and distances.

The GPS data analysed by Clarke et al. (2016) suggested that the total running volume of an average elite men's sevens game totals 1249 ± 348m. The average maximum velocity reached by elite men's sevens players is 8.7 ± 0.99m.s^{-1}, and maximum acceleration velocity was 4.2 ± 0.5m.s^{-2} (Clarke et al., 2016). 37.7 ± 5.8% of the running volume was spent running at 3.5m.s^{-1} or less, covering 483 ± 172m (Clarke et al., 2016). 15.6 ± 4.2% of running volume per game was spent running between 3.6m.s^{-1}and 5m.s^{-1}, covering 201 ± 79m (Clarke et al., 2016). 16.9 ± 4.3% of total running volume is spent running at 'sprint' velocity, assuming to be speeds exceeding 5m.s^{-1}, this covers a distance of 223.2m ± 104.7m per game (Clarke et al., 2016). Sprint bouts of elite men lasted a duration of 4.2 ± 1.6s which would be approximately 30-50m sprints (Clarke et al., 2016). The average total running volume performed in an elite women's sevens game totals 1078 ± 197m (Clarke et al., 2016). The maximum speed elite women reach during a game is 8.05 ± 0.55 m.s^{-1}, and a maximum acceleration velocity of 3.49 ± 0.38m.s^{-2} (Clarke et al., 2016). It was revealed that elite women 29.7 ± 0.34% of total running volume was performed at 3.5m.s^{-1} or less, covering a distance of 323 ± 87m. 11 ± 2.7% of the running volume was spent running between 3.6m.s^{-1} and 5m.s^{-1}, covering 120 ± 41m. 14.2 ± 2.8% of game running volume was spent at 'sprint' velocity assuming to be speeds above 5m.s^{-1} but not exceeding the average maximum velocity of 8.05m.s^{-1}, this covers approximately 148.6 ± 39.1m, with bouts being approximately 4.1 ± 0.44s in duration, which would cover up to approximately 30-40m. This speed information could be useful for prescribing individual speed targets for distances prior to applying breaking forces and target distances to stop their momentum as time effectively as possibly. Looking at the differences between genders and playing levels allows us to have some insight into what speeds players need to be able to decelerate from, and what distance or amount of time we should expect them to be able to decelerate and contribute to game play by either changing direction to evade or tackle defenders. Through GPS analysis vital information regarding low speed, short distance movements may be missed (Delaney et al., 2016). Short acceleration and deceleration efforts are often categorised as low velocity bouts, disregarding the high loading and energetic demands, especially during deceleration (Delaney et al., 2016).

Recommendations for Future Research

A DI could be devised similar to the lateral cutting index, as it was deemed as an appropriate measure for assessing lateral cutting ability (Shimokochi et al., 2013). Although the Shimokochi et al. (2013) study looked at only a few steps leading into the lateral cut and only base the cutting index on the actual cutting movement, this could be applied to decelerating over a set distance. For example, the speed of deceleration after a maximal sprint effort of a set distance (time taken for COM to stop) could be divided by the contact time of each step taken to decelerate. This could also be in reference to a specific distance, dividing the deceleration time by the distance covered. The focus could also just be on the three steps prior to the stop and factor in stride length and force of each step to look at more variables outside of temporal characteristics if using laboratory equipment. For example, a maximum speed for 10m with a defined deceleration zone to stop within, this could look like dividing the speed of deceleration by the contact time of each step in the deceleration zone. The magnitude of force for each step to decelerate, turn and re-accelerate back across the deceleration zone (shuttle style) could also reveal any relationship between higher force application to break, and more effective re-acceleration off the stop and turn during high velocity deceleration tasks. The protocol Smith et al. (2009) used to induce fatigue using isometric holds could be useful for here to do similar shuttle tasks under a fatigued state without adding extra volume on the subject's feet. Alternatively, similar to the 505 deficit proposed by Nimphius et al. (2016), a field based approach could be taken for ease of use for all teams without specialised equipment being required to use the scale. A field based method will ensure all teams can use and interpret the scale for easy implementation of drill and skill progressions and regressions based on level of proficiency. This could also provide further insight to other trainable sub qualities that could improve deceleration performance.

Aside from different ways of measuring deceleration and what could affect this component of COD, it is firstly of high importance to understand if and to what extent deceleration can be trained. We know that deceleration is eccentric and highly demanding, and the usual culprit for non-contact ACL rupture (Dalen et al., 2016; Griffith, 2005; Harper et al., 2018; Hart et al., 2014; Hewit et al., 2011; Kovacs et al., 2008; Lakomy & Haydon, 2004; Lockie et al., 2013; Nimphius, 2014; Russell et al., 2016; Sheppard et al., 2014; Smith et al., 2009; Spiteri et al., 2015; Terblanche & Venter, 2009). The inclusion of this component of physical preparedness would be highly valuable in a training program for team sports as this is very specific and has been reported as the crucial aspect of COD that determines superior COD ability. We need to know whether or not focusing on deceleration movement and technique from high speeds, similar to what would be expected on the field will elicit improvements in COD tasks.

Conclusion

Agility and COD are crucial skills for team sports, however little time is often spent on improving the ability to decelerate as an explicit skill in the way we would focus on the ability to accelerate. With a large emphasis on acceleration, neglecting deceleration ability as a training focus could decrease athletic performance and increase potential for injury. As athletes develop, increase body mass, skill level, speed and strength, the ability to control the body through a COD is altered. Unplanned and rapid changes in direction are the most likely cause of non-contact injuries in team sports, due to the athlete being unable to control momentum effectively and pay attentional focus to relevant external stimuli. An athlete who can subconsciously move using superior movement strategies will feel as if they have more time to search for and react to relevant external stimuli, making them more competitive on the field, and be less likely to become injured. An investigation into rapid deceleration efforts from high velocity sprinting could be an advantageous to improve player preparation, specific to individual momentum and breaking force requirements in rugby codes.

Chapter Three

Methods

Experimental Approach to the Problem

A longitudinal experimental approach was used to investigate the effect of a training intervention focusing on deceleration drills and rapid deceleration efforts. A single group, non-randomised pre-post-test experimental design was used, investigating pre and post intervention outcome measures of male and female club and regional representative level rugby players. This research design was used with respect to the number of participants available to take part in the study. The participants underwent baseline testing prior to the commencement of a training intervention period. The intervention was introduced as a comprehensive warm-up during pre-season fitness training. Several baseline performance measures were collected to investigate the efficacy of deceleration drills on COD speed.

Participants

Seven male club level rugby players (age: 24.4 ± 7.4 years; height: 181 ± 7cm; mass: 87.5 ± 7.7kg) and five female regional representative rugby players (age: 23 ± 5.7 years, mass: 71.3 ± 13.8kg) were recruited through the Suburbs Sports Club 15s rugby team and the Bay of Plenty Women's 15s representative rugby team to take part in this study during a period of pre-season training. These participants underwent pre and post intervention testing. Initially there were 28 participants in the male group, and 8 participants in the female group who took part in the training intervention. Unfortunately most of these participants were not included in analysis as they did failed to attend both pre and/or post intervention testing sessions due to other commitments. Participants were included in the study if they were free from injury, had experience playing rugby at club level or better for at least two years, and were going to attend pre-season training sessions two times per week for 6 weeks prior to competition period commencing. Data was used for analysis if participants attended both pre and post training intervention data collection sessions.

Experimental Protocol

The study was conducted over a six week period. Participants underwent baseline testing at the start of week 1 and the details of the training intervention were explained during this session. The training intervention was implemented following the initial baseline testing session twice per week. Performance testing at baseline and post intervention were performed in the same order at approximately the same time under the same conditions, with tests having the highest energetic demands first, and least demanding at the end of the session to reduce impact on subsequent performances (Dawes & Roozen, 2012; Joyce & Lewindon, 2014). Testing occurred following a warm-up, beginning with speed and COD, strength, jumping tasks, finishing with running endurance (Dawes & Roozen, 2012; Joyce & Lewindon, 2014).

The training intervention was integrated as a 20-30 minute warm-up protocol. During the first week the protocol took 30 minutes with explanation and correction of exercises, which thereafter only took 20 minutes to complete as this was the dedicated time slot available within the session for the protocol to take place. The focus was on learning the deceleration skill and performing rapid decelerations from near maximal sprint velocities. It has been reported that regular 15 minute agility training sessions can elicit improvements in this quality (Joyce & Lewindon, 2014). Based on this, it was felt that the duration of the warm-up protocol would be able to produce adaptations during the 6 week intervention period.

Participants performed a specific warm-up to prepare for maximal sprinting and deceleration (Table 3.1 and Appendix G and H). This included a range of sprint drills, deceleration and COD drills. Deceleration drills included bound and stick drills (1, 2, 3 strides), fall and stop, drop stick, drop stick and jump, and backward skipping. Participants were instructed to adopt the desirable kinematics required for superior deceleration performance using the following cues legs in front of the body to apply breaking forces, lower COM, long contacts to absorb force, brace for impact, wide base of support, sit in the heels, as described in Chapter Two.

Once drills were complete, participants performed maximal effort sprints for 10m and 20m into a deceleration zone where they were required to decelerate as fast as possible, attempting not to cross the stop cone placed 3m from the end of the sprint zone. Distances were determined through pilot testing and information provided by the literature review. Participants were encouraged to alternate lead deceleration legs each repetition, the lead deceleration leg was distinguished by the leg that was in front when at a complete stop after decelerating. Participants were encouraged to use a 3-5 step stop strategy for 10 and 20m sprints. It was expected that it would take several sessions to refine the strategy to stop momentum to a 3-5 step strategy. A walk back recovery was used due to time constraints within the permitted time allocation for the warm-up protocol. This was approximately 60s recovery for 10m efforts, and 120s for 20m efforts.

Table 3.1 Deceleration Training Intervention Warm-up Protocol

Mobility Exercise	Sets	Reps	Rest
Knee to chest walk	1	10m	-
Heel to butt walk	1	10m	-
Lunge walk	1	10m	-
Squat walk	1	10m	-
Hamstring Sweep	1	10m	-
Leg Swing	1	10m	-
Running Technique Drills	**Sets**	**Reps**	**Rest**
Low skips forward	1	10m	-
Low skips backward	1	10m	-
Medium skips forward	1	10m	-
Medium skips backward	1	10m	-
A-Skip	2	10m	-
B-Skip	2	10m	-
Deceleration Drills	**Sets**	**Reps**	**Rest**
Drop and Stick – Squat	1	6	-
Drop and Stick – Single leg	1	3ea	-
Drop and Stick – Lunge	1	3ea	-
Drop, Stick and Jump – Squat	1	6	-
Drop, Stick and Jump Single Leg	1	3ea	-
Drop, Stick and Jump – Lunge	1	3ea	-
Fall and Stop – 3 Steps	1	3ea	-
Fall and Stop – 2 Steps	1	3ea	-
Fall and Stop – 1 Step	1	3ea	-
Bound and Stick – 1 Step	2	10m	-
Bound and Stick – 2 Steps	2	10m	-
Bound and Stick – 3 Steps	2	10m	-
Rapid Decelerations	**Sets**	**Reps**	**Rest**
10m Sprint 3m Break Zone	1	4	Walk back
20m Sprint 3m Break Zone	1	4	Walk back

ea=each leg

Appendix G contains still images of phases of each drill, and Appendix H has video of the protocol described in Table 3.1.

Participant Characteristics

Age and playing experience data was collected from the participants as part of a pre-participation questionnaire (Appendix F). Players in the male group had 10.9 ± 5.5 years playing experience, attended 3.3 ± 1.4 training sessions per week, including pre-season rugby trainings and self-prescribed strength and conditioning training. Seven of the male players had been involved in the 15s rugby code, three in Rugby Sevens, and three in the touch rugby code. Players from the female group had 6.8 ± 5.9 years playing experience, attended 4.8 ± 0.8 training sessions per week, including pre-season rugby trainings and strength and conditioning sessions with the regional strength and conditioning coach. The pre-season strength and conditioning sessions involved building general strength, and correcting movement imbalances. The male group performed all baseline measures detailed below. The female group were only able to complete the 505 COD test and body mass measures due to time constraints.

Measures

Speed

10m sprint time was measured using Fusion Sport, Smart Speed Lite speed timing gates (SmartSpeed, Fusion Sport, Brisbane, Australia). Participants were required to adopt a standing start position with one foot forward determined by the individual, with the start point 50cm behind the start gate. A static start was performed, with no momentum generated prior to passing the start gate. Participants were instructed to sprint as fast as possible and pass through the finish gate at the 10m mark at maximal speed, slowing down well beyond the finish gate to obtain the quickest time with little deceleration before the end of the speed zone. Each participant was allowed two attempts through the timing gates, where the highest speed was used for data analysis. 10m sprint time has been reported as a highly reliable measure of speed, with low variability between tests (ICC=0.905, CV=2.2%) (Dos'Santos, Thomas, Jones, et al., 2018)

Change of Direction

The 505 COD test involved a 10m acceleration leading into a 5m deceleration, turn 180° and re-acceleration back 5m according to previously described methods (Dawes & Roozen, 2012; Nimphius, 2014). This test is highly demanding with regard to breaking force application, and was expected to provide a clear distinction as to whether the implementation of the protocol used in this study elicited a change in performance. This test was the most appropriate for assessing rapid deceleration from sprint speed compared to other commonly used tests like the T-Test and the AFL agility test which have higher numbers of turns or multiple movement tasks (Dawes & Roozen, 2012; Spiteri et al., 2015). The 505 COD test has a high breaking force demand due to the large amount of momentum able to be generated with a high velocity entry, as well as demanding kinematics required to be effective at stopping to turn and reaccelerate (Nimphius, 2014; Nimphius et al., 2018; Nimphius et al., 2016).

505 COD was measured using the Fusion Sport, Smart Speed Lite speed timing gates, set up side by side for two performances occurring simultaneously. This set up was decided on for efficiency of running the testing session, ensuring all tests could be completed within the allotted timeframe. This decision was also to eliminate a participant attempting to modify entry velocity to reduce breaking force demands, by introducing competition and to maximise effort and performance. The 505 COD test has excellent in session and between session reliability from both flying and stationary starts (flying start in session ICC=0.90-0.97, between session ICC=0.951) (Barber et al., 2016). The flying start is defined by the inclusion of the 10m sprint leading into the timing gates, whereas the stationary start is defined by starting at the timing gate (Barber et al., 2016). Momentum is higher during the flying start and may require some familiarisation, which is where any variability between tests may occur, this is eliminated after practice attempts (Barber et al., 2016). Two attempts were performed, and best performance used for analysis to allow for variability due to familiarisation.

It has been suggested that a COD deficit provides an additional layer of validity with COD testing (Nimphius et al., 2018; Nimphius et al., 2016). This can be done by comparing the time taken to complete a linear sprint with the time taken to complete a COD task of the same distance (Nimphius et al., 2018; Nimphius et al., 2016). The difference between times is described as the 505 deficit and can be used to understand an athletes 505 COD ability (Nimphius et al., 2018; Nimphius et al., 2016). Spiteri et al. (2018) suggested the inclusion of body mass data when analysing COD performance due to momentum being a differentiating factor between individual performances, this will be addressed with the development of a potential DI in this thesis.

The a possible calculation for the proposed DI using the 505 COD test could be momentum generated during the 10m approach, divided by the time taken to complete the remaining portion of the 505 test. If coaches are unable to set up timing gates at 0m, as well as the 505 COD gate set up, it could be possible to use maximal 10m speed momentum with the 505 time, reliability of either of these methods will have to be understood through future research.

Vertical jump

Vertical jump height was measured using a Jump Mat (SmartSpeed, Fusion Sport, Brisbane, Australia). Both bilateral and single leg take-offs were measured and required a bilateral stance for landing, pushing off unilaterally and landing bilaterally during single leg attempts. Vertical jump height has been reported as a valid and reliable measure of lower limb strength, especially with the use of vertical jump height measurement devices (Garcia-Lopez, Morante, Ogueta-Alday, & Rodriguez-Marroyo, 2013). The use of a similar contact mat for jump height performance measurement has been reported as reliable between sessions (ICC=0.97-0.98, SEM=2cm, CV=4.44-6.3%) (Garcia-Lopez et al., 2013). Changes in jump performance using the contact mat greater than 2cm should be considered as a valid improvement in performance (Garcia-Lopez et al., 2013). Vertical jump asymmetry has been calculated using the following equation in Microsoft excel: Step one: =DEGREES(ATAN(left/right))=n, Step two: =((45-n)/90)x100=Asymmetry (Bishop et al., 2016; Zifchock et al., 2008). This was chosen due to its validity irrespective of the dominant value or value used first, which is important for detecting meaningful change in the small population used in this study (Bishop et al., 2016; Zifchock et al., 2008). This asymmetry calculation has been reported as highly reliable and a measure of true asymmetry compared to other previous methods of calculating asymmetry or deficit between limb performances (Bishop et al., 2016; Zifchock et al., 2008). The closer the percentage of asymmetry to 0% the more symmetrical the performance in each limb.

Reactive Strength

The Fusion Sport Jump Mat was also used to test the bounce drop jump from 30cm. The bounce drop jump is a reactive strength test, evaluating the ability to apply force quickly (Joyce & Lewindon, 2014; Young, 2006). During the bounce drop jump the athlete drops from the 30cm box on to the mat and aims to have a short contact time on the ground with a maximal jump (Joyce & Lewindon, 2014). The jump mat incorporates body mass when looking at the captured data and retrospectively calculates a number of additional measures adjusted to each individuals body mass. Contact time, flight time, jump height, RSI (contact time/flight time), PPO, power: mass ratio, leg stiffness, Flight time:Contact time (FT:CT), and net concentric impulse were all collected by the jump mat. RSI was the main measure of interest used for analysis of the bounce drop jump. RSI modified using contact time and flight height (estimated by flight time with this calculation) has been reported as highly reliable (ICC=0.96, CV=7.6-9.3%) (Suchomel, Bailey, Sole, Grazer, & Beckham, 2015). Participants were instructed to utilise a fast contact time, with the subsequent vertical jump being as high as possible to provide the best performance with regard to 30cm box height and high eccentric loading and expected SSC movement required for rugby players (Joyce & Lewindon, 2014; Struzik, Juras, Pietraszewski, & Rokita, 2016; Young, Pryor, & Wilson, 1995). Participants performed 2 trials and the best trial was used for analysis.

Maximal Lower Body Strength

A barbell back squat to box was used to test maximal lower body strength (Argus, Gill, Keogh, McGuigan, & Hopkins, 2012; Banyard, Nosaka, & Haff, 2016). The box was adjusted for each individual to allow the top of the thighs to be parallel to the floor while briefly seated. The box squat was chosen for ease of use with large groups of participants to achieve the same degree of hip and knee flexion post intervention (Argus et al., 2012). Each participant worked up to a one repetition maximum (1RM) squat after a warm-up and familiarisation of the movement, which has occurred after speed testing and comprehensive sprint warm-up. Each participant had up to 5 attempts with full recovery in between attempts, to reach a 1RM, either by attempting previously unsuccessful lifts, or increasing in weight selected by the participant (Banyard et al., 2016). The heaviest weight successfully lifted after 5 maximal attempts was recorded (Banyard et al., 2016). The 1RM back squat is a highly reliable and valid measure of strength (ICC=0.99, CV=2.1%) (Argus et al., 2012; Banyard et al., 2016).

Horizontal Jump

Horizontal jump was measured for both bilateral take-off, and single leg take-off. This was measured using a measuring tape secured to the floor surface. Each participant was required to adopt a static start with toes behind the 0cm line, landing on two feet for both bilateral and single leg efforts (Reid, Dolan, & DeBeliso, 2017). Measurement was taken from the heel, from the rear leg if a split stance was adopted for landing. The participant had to stick the landing to have the jump recorded (Reid et al., 2017). If they did not stick the landing, they were allowed to have an additional attempt after adequate recovery. Participants were able to perform 1 practice and two recorded attempts for each jump type, the best distance was used for analysis. It has been reported that the standing horizontal jump is highly reliable within and between testing sessions (ICC=0.99, CV=1.97%), with a maximal jump distance typically able to be achieved within 3 jumps (Reid et al., 2017). Horizontal jump asymmetry has been calculated using the equation above mentioned for vertical jump asymmetry (Bishop et al., 2016; Zifchock et al., 2008).

Statistical Analysis

A Paired T-Test was used to compare differences between pre and post intervention measures. Significance was set at $p \leq 0.05$. Effect size (ES) as well as Hedges' g ES for small populations were used to determine the meaningfulness of the changes (Ellis, 2010). The magnitude of Hedges g was classified using the following scale: 0–0.19=trivial effect, 0.20–0.49=small effect, 0.50–0.79=moderate effect and ≥0.80=large effect, and will be used for discussing the results due to the small population in this study (Cohen, 1988). Smallest worthwhile change (SWC), calculated by multiplying 0.2 by the between subject standard deviation pre intervention for each test, based on Cohen's ES of 0.2 being small (Cohen, 1988). SWC was important for analysis at the individual level to provide further insight to meaningful performance change with a small subject pool. Pearson product moment correlations were determined using pooled data from pre and post intervention to understand the relationship between key performance variables and the 505 COD test. The strength of the correlation coefficient (*r*) was described as classified by Hopkins (2002): 0.5-0.69=high correlation, 0.7-0.89=very high correlation, and 0.9-1.0=an almost perfect correlation.

Chapter Four

Results

Session Adherence

A mean attendance of 70 ± 8% (mean ± SD) was observed in the male group (Appendix I) and 100% reported for the female group.

Change of Direction

The participant characteristics at baseline for key variables are shown in Table 4.1. The male participants had greater playing experience (10.9 ± 5.5 years) and body mass (87.5 ± 7.7kg). The female players trained more times per week (4.8 ± 0.8 days).

	Age (years)	Playing Experience (years)	Training days per week (days)	Body Mass (kg)	505 COD Time (s)
Group (n=12)	23.7 ± 6.5	9.2 ± 5.8	3.9 ± 1.3	80.8 ± 13.1	2.43 ± 0.17
Female (n=5)	22.6 ± 5.7	6.8 ± 5.9	4.8 ± 0.8	71.3 ± 13.8	2.50 ± 0.18
Male (n=7)	24.4 ± 7.4	10.9 ± 5.5	3.3 ± 1.4	87.5 ± 7.7	2.38 ± 0.17

No significant changes from pre to post intervention were observed in the 505 COD test (Table 4.2).

Table 4.2 Pre-Post Intervention 505 Change of Direction Test Results Mean ± SD

	Pre (s)	Post (s)	Change (s)	% Change	ES	Hedges ES	p-value	SWC (s)
Group (n=12)	2.43 ± 0.17	2.41 ± 0.17	0.003 ± 0.07	0.1 ± 2.8	0.09	0.06	0.44	0.03
Female (n=5)	2.50 ± 0.18	2.48 ± 0.21	0.01 ± 0.09	-0.6 ± 3.3	0.08			0.03
Male (n=7)	2.38 ± 0.17	2.36 ± 0.14	0.02 ± 0.06	0.6 ± 2.4	0.10			0.04

SWC=Smallest Worthwhile Change, ES=Effect Size, Hedges ES=Hedges' g Effect Size

Table 4.3 presents individual results for pre to post intervention 505 COD performance. Using SWC, improvements in 505 COD time greater than 0.03s were shown in four out of twelve individuals (M1, M7, F1, F3). There were decreases in performance that also met the SWC threshold (M4, M5, F3), the remaining performances were maintained pre to post intervention (M2, M3, M6, F3, F4).

Table 4.3 Pre-Post Intervention 505 Change of Direction Test Individual Results

Participant	Pre (s)	Post (s)	% Change
M1	2.40	2.29	**+4.6**
M2	2.49	2.48	+0.6
M3	2.59	2.59	+0.1
M4	2.17	2.22	**-2.3**
M5	2.14	2.19	**-2.1**
M6	2.41	2.39	+0.8
M7	2.45	2.39	**+2.5**
F1	2.44	2.39	**+2.0**
F2	2.77	2.85	**+2.8**
F3	2.58	2.43	**+5.6**
F4	2.34	2.36	+1.0
F5	2.36	2.38	+0.8

Bold results indicate performance change greater than the smallest worthwhile change, a + indicates increased performance

Body Mass

Table 4.4 presents pre to post intervention body mass changes with a significant increase in body mass from pre to post training intervention.

Table 4.4 Pre-Post Intervention Body Mass Results Mean ± SD (male)

	Pre (kg)	Post (kg)	Change (kg)	% Change	ES	Hedges ES	p-value	SWC (kg)
Group (n=12)	80.8 ± 13.1	82.5 ± 13.1	1.8 ± 1.5	2.2 ± 1.8	0.13	0.13	0.00	2.6
Male (n=7)	87.5 ± 7.7	89.9 ± 7.7	2.4 ± 1.02	2.8 ± 1.3	0.31			1.6
Female (n=5)	71.34 ± 13.8	72.2 ± 12.6	0.9 ± 1.7	1.5 ± 2.3	0.06			2.8

SWC=Smallest Worthwhile Change, ES=Effect Size, Hedges ES=Hedges' g Effect Size

Four individuals (M4, M6, M7, F3) increased body mass greater than the pooled results SWC of 2.6kg (Table 4.3). Only one participant decreased body mass (F3), however, this change did not meet the SWC threshold for the pooled results. The SWC threshold for the males was 1.6kg, which six out of seven increased beyond post intervention.

Table 4.5 Pre-Post Intervention Body Mass Individual Results

Participant	Pre (kg)	Post (kg)	% Change
M1	96.5	98.8	**+2.4**
M2	82.6	85.1	**+3.0**
M3	95.2	97.0	**+1.9**
M4	78.2	81.4	**+4.1**
M5	81.6	82.2	+0.7
M6	83.4	87.2	**+4.6**
M7	95.0	97.6	**+2.7**
F1	73.5	75.1	**+2.2**
F2	94.6	93.1	-1.6
F3	62.3	65.1	**+4.5**
F4	62.9	64.3	+2.2
F5	63.4	63.4	0.0

Bold results indicate performance change greater than the smallest worthwhile change, a + indicates increased body mass

Maximal Lower Body Strength

There was a significant strength increase from pre to post intervention (Table 4.6). Most participants improved greater than the SWC threshold in the 1RM squat, as well as relative strength.

Table 4.6 Pre-Post Intervention Strength Results Mean ± SD (male)

	Pre	Post	Change	% Change	ES	Hedges ES	p-value	SWC (kg, kg/mass)
Squat 1RM	116.7 ± 26.6	132.9 ± 20.6	32.9 ± 40.7	17.9 ± 15.9	0.61	0.61	0.03	5.32
Relative Strength	1.4 ± 0.4	1.5 ± 0.3	0.3 ± 0.4	14.7 ± 15.7	0.32	-0.07	0.06	0.07

SWC=Smallest Worthwhile Change, ES=Effect Size, Hedges ES=Hedges' g Effect Size

Five out of seven performances (M2, M3, M5, M6, M7) were improved beyond the SWC threshold for both 1RM squat and relative strength (Table 4.7).

Table 4.7 Pre-Post Intervention Strength Individual Results (male)

	1RM Squat			Relative Strength		
Participant	Pre (kg)	Post (kg)	% Change	Pre (kg/mass)	Post (kg/mass)	% Change
M2	80	110	**37.5**	0.97	1.3	**33.5**
M3	110	150	**36.4**	1.16	1.6	**33.8**
M4	130	130	0.0	1.66	1.6	**-3.9**
M5	160	170	**6.3**	1.96	2.1	**5.5**
M6	110	130	**18.2**	1.32	1.5	**13.0**
M7	110	120	**9.1**	1.16	1.2	**6.2**

Bold results indicate performance change greater than the smallest worthwhile change

Horizontal Jumps

Horizontal jump performance was not improved from pre to post intervention. The SWC value indicated for each jump type suggested that any performance greater than 5.77cm for bilateral, 4.88cm for right, and 4.44cm for left leg indicated a SWC.

Table 4.8 Pre-Post Intervention Horizontal Jump Results Mean ± SD (male)

	Pre	Post	Pre-Post Change	% Change	ES	Hedges ES	p-value	SWC
Bilateral Horizontal	228.3 ± 28.8	225.4 ± 21.9	2.9 ± 9.9	-0.9 ± 4.2	-0.10	-0.10	0.47	5.77
Right Horizontal	192.9 ± 24.4	187.9 ± 22.9	5 ± 16.3	-2.2 ± 8.2	-0.21	-0.20	0.45	4.88
Left Horizontal	190 ± 22.2	185.6 ± 18.8	4.4 ± 5.5	-2.2 ± 2.6	-0.20	-0.20	0.08	4.44

SWC=Smallest Worthwhile Change, ES=Effect Size, Hedges ES=Hedges' g Effect Size

Table 4.9 presents the individual results for each jump type. For bilateral performance, five individuals (M1, M2, M4, M5, M6) had reduced performance, while two increased performance, one of which was considered a worthwhile change (M7). For right leg take-off performance, four participants improved performance on right leg take-off, two of these performances were greater than the SWC value, while three performances reduced (M3, M4, M6). Left leg take-off performance was reduced for all participants from pre to post intervention, with three individuals (M1, M5, M7) greater than the SWC value.

Table 4.9 Pre-Post Intervention Horizontal Jump Individual Results (male)

	Bilateral Take-off			Right Leg Take-off			Left Leg Take-off		
Participant	Pre (cm)	Post (cm)	% Change	Pre (cm)	Post (cm)	% Change	Pre (cm)	Post (cm)	% Change
M1	280	265	**-5.4**	216	217	0.5	230	217	**-5.7**
M2	208	206	-1.0	155	160	**3.2**	168	170	1.2
M3	202	203	0.5	180	170	**-5.6**	174	170	-2.3
M4	222	218	-1.8	193	178	**-7.8**	188	186	-1.1
M5	256	243	**-5.1**	218	220	0.9	202	192	**-5.0**
M6	220	218	-0.9	214	180	**-15.9**	198	199	0.5
M7	210	225	**7.1**	174	190	**9.2**	170	165	**-2.9**

Bold results indicate performance change greater than the smallest worthwhile change

Table 4.10 presents the between limb asymmetry from pre to post intervention indicated by the results of the single leg horizontal jump test. From pre to post intervention three participants have reduced performance asymmetry (M1, M2, M3), two of these participants have reduced this asymmetry to becoming perfectly balanced, indicated by 0% asymmetry (Table 4.10).

Table 4.10 Horizontal Jump Left to Right leg Performance Asymmetry (male)

	Pre Horizontal Jump			Post Horizontal Jump		
Participant	Right	Left	% Imbalance	Right	Left	% Imbalance
M1	216	230	-2.0	217	217	**0.0**
M2	155	168	-2.6	160	170	**-1.9**
M3	180	174	1.1	170	170	**0.0**
M4	193	188	0.8	178	186	-1.4
M5	218	202	2.4	220	192	4.3
M6	214	198	2.5	180	199	-3.2
M7	174	170	0.7	190	165	4.5

Negative results indicate a left leg dominance, **Bold** results indicate a reduction in deficit between legs, the closer to 0% suggests less asymmetry

Vertical Jumps

There was a significant change pre to post intervention with single leg performance, but no significant change in bilateral performance (Table 4.11). The SWC value suggested that performance changes greater than 1.63cm from a right leg take off, and 0.99cm from a left leg take off were deemed worthwhile. Bilateral performances that improved greater than 1.85cm are also above the threshold for being worthwhile. Table 4.11 shows improvements across all vertical jump measures that exceeded the indicated SWC thresholds.

Table 4.11 Pre-Post Intervention Vertical Jump Results Mean ± SD (male)

	Pre	Post	Change	% Change	ES	Hedges ES	p-value	SWC
Bilateral Vertical	47.5 ± 9.2	48.7 ± 6.2	1.2 ± 3.7	3.8 ± 8.0	0.13	0.13	0.41	1.85
Right Vertical	25.9 ± 8.1	28.9 ± 6.3	3.0 ± 3.37	15.8 ± 18.9	0.37	0.36	0.06	1.63
Left Vertical	26.2 ± 4.9	30.3 ± 5	4.1 ± 1.5	16.3 ± 6.5	0.83	0.82	0.00	0.99

SWC=Smallest Worthwhile Change, ES=Effect Size, Hedges ES=Hedges' g Effect Size

Individual vertical jump results from pre to post intervention are presented in Table 4.12. There were three performances that exceed the SWC value for bilateral vertical jump (M2, M3, M4). Right leg take-off shows five performances exceeding the SWC value (M2, M3, M4, M5, M6), all performances from a left leg take-off improved beyond the SWC value. One individual (M1) reduced performance beyond the SWC value in bilateral and right leg take-off, but increased performance in the left leg take-off.

Table 4.12 Pre-Post Intervention Vertical Jump Individual Results (male)

	Bilateral Take-off			Right Leg Take-off			Left Leg Take-off		
Participant	Pre (cm)	Post (cm)	% Change	Pre (cm)	Post (cm)	% Change	Pre (cm)	Post (cm)	% Change
M1	61.4	56.0	**-8.8**	36.1	33.0	**-8.6**	32.9	35.0	**6.4**
M2	38.3	45.0	**17.5**	18.8	24.0	**27.7**	22.7	28.0	**23.3**
M3	41.6	44.0	**5.8**	22.4	26.0	**16.1**	23.5	27.0	**14.9**
M4	45.0	48.0	**6.7**	27.6	30.0	**8.7**	24.1	30.0	**24.5**
M5	59.9	59.0	-1.5	35.0	40.0	**14.3**	33.4	39.0	**16.8**
M6	42.6	44.0	3.3	14.0	21.0	**50.0**	21.2	25.0	**17.9**
M7	43.5	45.0	3.4	27.3	28.0	2.6	25.4	28.0	**10.2**

Bold results indicate performance change greater than the smallest worthwhile change

Table 4.13 presents the between limb asymmetry from pre to post intervention indicated by the results of the single leg vertical jump test. From pre to post intervention all participants reduced the amount of asymmetry between legs, with two participants reducing this to 0%, and one reducing this to 0.8%.

Table 4.13 Vertical Jump Left to Right leg Performance Asymmetry (male)

	Pre Vertical Jump			Post Vertical Jump		
Participant	Right	Left	% Imbalance	Right	Left	% Imbalance
M1	36.1	32.9	3.0	33	35	**-1.9**
M2	18.8	22.7	-6.0	24	28	**-4.9**
M3	22.4	23.5	-1.5	26	27	**-1.2**
M4	27.6	24.1	4.3	30	30	**0.0**
M5	35	33.4	1.5	40	39	**0.8**
M6	14	21.2	-12.8	21	25	**-5.5**
M7	27.3	25.4	2.3	28	28	**0.0**

Negative results indicate a left leg dominance, **Bold** results indicate a reduction in deficit between legs, the closer to 0% suggests less asymmetry

Speed

Speed data is shown in Table 4.14. There were significant changes pre to post intervention with regard to momentum (kg.m/s) during the 10m maximal sprint. SWC values also indicated that a number of performances across the speed related variables improved greater than the indicated threshold for worthwhile performance change.

Table 4.14 Pre-Post Intervention Speed Results Mean ± SD (male)

	Pre	Post	Pre-Post Change	% Change	ES	Hedges ES	p-value	SWC
10m Speed	1.8 ± 0.1	1.8 ± 0.1	0.02 ± 0.05	-1.1 ± 2.6	0.24	0.11	0.27	0.02
10m m/s	5.5 ± 0.3	5.5 ± 0.3	0.07 ± 0.15	1.2 ± 2.6	0.26	0.23	0.28	0.05
Momentum (kg.m/s)	477.3 ± 40.8	497.2 ± 53.7	19.83 ± 13.82	4 ± 2.5	0.49	0.49	**0.01**	8.17

SWC=Smallest Worthwhile Change, ES=Effect Size, Hedges ES=Hedges' g Effect Size

Table 4.15 shows the individual results for speed related variables. Six out of seven increased momentum beyond the SWC value (M1, M2, M3, M4, M6, M7). Three out of seven improved performance in 10m speed and 10m m/s (M1, M3, M7).

Table 4.15 Pre-Post Intervention Speed Individual Results (male)

	10m Speed (s)			10m m/s (m)			Momentum (kg.m/s)		
Participant	Pre (s)	Post (s)	% Change	Pre (m)	Post (m)	% Change	Pre (kg.m/s)	Post (kg.m/s)	% Change
M1	1.74	1.65	**-5.0**	5.75	6.05	**5.3**	554.60	597.70	**7.8**
M2	1.86	1.87	0.6	5.38	5.34	-0.6	444.09	454.59	**2.4**
M3	1.99	1.94	**-2.7**	5.03	5.16	**2.7**	478.39	500.77	**4.7**
M4	1.78	1.82	**2.0**	5.62	5.51	**-2.0**	439.33	448.24	**2.0**
M5	1.75	1.75	-0.2	5.71	5.72	0.2	466.29	470.52	0.9
M6	1.84	1.85	0.6	5.43	5.40	-0.6	453.26	471.10	**3.9**
M7	1.88	1.82	**-3.4**	5.32	5.50	**3.5**	505.32	537.15	**6.3**

Bold results indicate performance change greater than the smallest worthwhile change

Table 4.16 examines the 505 deficit pre to post intervention (Nimphius et al., 2016). Three participants (M1, M2, M6) reduced the 505 deficit post intervention.

Table 4.16 505 Deficit (male)

	Pre 505 Deficit			Post 505 Deficit		
Participant	Pre 10m	Pre 505	Deficit	Post 10m	Post 505	Deficit
M1	1.74	2.40	0.66	1.65	2.29	**0.64**
M2	1.86	2.49	0.63	1.87	2.48	**0.60**
M3	1.99	2.59	0.60	1.94	2.59	0.65
M4	1.78	2.17	0.39	1.82	2.22	0.40
M5	1.75	2.14	0.39	1.75	2.19	0.44
M6	1.84	2.41	0.57	1.85	2.39	**0.54**
M7	1.88	2.45	0.57	1.82	2.39	0.57

Bold performances indicate an improved ability to change direction as per Nimphius et al. (2016)

Correlations

Pre intervention correlations to 505 COD performance and other performance variables are shown in Table 4.17. Pre training intervention, 10m speed and 10m m/s had a very high correlation to 505 COD performance. 1RM Squat was also very highly correlated to 505 COD performance, while relative strength showed an almost perfect relationship with 505 COD performance.

Table 4.17 Pre Intervention Correlations (Male)

N=7 Squat (1RM Squat, Relative Strength N=6)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Weight (1)	1	-.381	-.362	.841*	-.656	.115	-.073	.107	.151	.237	.21	.098	.738	-.111	-.284	-.538
10m (2)		1	.999**	.179	.790*	.817*	.627	.738	.739	.598	.656	.459	.163	-.188	.597	.763
10m m/s (3)			1	.198	.790*	.836*	.643	.757*	.763*	.623	.68	.487	.185	-.183	.627	.788
Momentum (kg.m/s) (4)				1	-.246	.603	.287	.551	.591	.593	.603	.365	.886**	-.252	.061	-.2
505 (5)					1	.475	.543	.391	.529	.51	.472	.501	-.286	.363	.803	.920**
Horizontal jump (6)						1	.751	.933**	.959**	.767*	.886**	.575	.568	-.314	.862*	.910*
Right horizontal (7)							1	.866*	.761*	.421	.571	.217	.03	-.133	.791	.794
Left horizontal (8)								1	.851*	.558	.692	.363	.433	-.443	.759	.827*
Vertical jump (9)									1	.863*	.962**	.679	.531	-.069	.935**	.901*
Right vertical (10)										1	.926**	.919**	.62	.264	.783	.712
Left vertical (11)											1	.768*	.612	.041	.816*	.754
RSI (12)												1	.524	.374	.641	.614
PPO (13)													1	-.324	-.215	-.378
Leg stiffness (14)														1	.647	.503
Squat 1RM (15)															1	.961**
Relative strength (16)																1

* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).
Performance measures are labelled as 1-16 for clear presentation of the data, duplicate data is omitted.

Table 4.18 shows post intervention correlations to 505 COD performance and other variables analysed during this study. The 10m time and 10m m/s were still very highly correlated to 505 COD performance. Vertical jump from bilateral, right and left leg take offs were also very highly correlated to 505 COD performance post intervention. RSI was very highly correlated to 505 COD performance post intervention.

Table 4.18 Post Intervention Correlations (Male)

N=7	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Weight (1)	1	.099	.134	.862*	-.475	.23	.134	-.005	-.14	-.142	-.169	-.072	.561	.307	-.25	-.621
10m (2)		1	.999**	.589	.75	.977**	.872*	.763*	.834*	.677	.765*	.929**	.643	.866*	-.019	-.003
10m m/s (3)			1	.617	.722	.982**	.871*	.773*	.834*	.672	.763*	.932**	.675	.863*	-.02	-.02
Momentum (kg.m/s) (4)				1	-.014	.681	.538	.397	.304	.213	.243	.414	.784*	.686	-.233	-.523
505 (5)					1	.664	.703	.556	.747	.722	.721	.772*	.157	.578	.248	.447
Horizontal jump (6)						1	.930**	.777*	.846*	.69	.769*	.917**	.718	.888**	.093	.029
Right horizontal (7)							1	.652	.899**	.828*	.851*	.878**	.647	.790*	.415	.329
Left horizontal (8)								1	.627	.331	.478	.744	0.383	.758*	.064	.08
Vertical jump (9)									1	.921**	.983**	.964**	.661	.551	.464	.477
Right vertical (10)										1	.965**	.836*	.625	.367	.584	.574
Left vertical (11)											1	.921**	.66	.433	.497	.516
RSI (12)												1	.692	.666	.251	.28
PPO (13)													1	.431	.123	-.108
Leg stiffness (14)														1	-.117	-.176
Squat 1RM (15)															1	.912**
Relative strength (16)																1

* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).
Performance measures are labelled as 1-16 for clear presentation of the data, duplicate data is omitted.

Table 4.19 shows correlations between pooled data from pre and post intervention to investigate relationships 505 COD performance as a component of performance and other variables analysed during this study. Relative strength and 10m and 10m m/s were very highly correlated to 505 COD performance. Horizontal jump from bilateral and right leg, vertical jump from bilateral, right and left leg take-offs, RSI and 1RM squat had a high correlation to 505 COD performance.

Table 4.19 Correlations – All Performances (Male**)**

N=14 (1rm Squat, Relative Strength N=13)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Weight (1)	1	-.113	-.077	.849**	-.553*	.151	.007	.035	.048	.105	.087	-.009	.666**	.021	-.143	-.490
10m (2)		1	.998**	.428	.768**	.860**	.722**	.720**	.762**	.634*	.695**	.720**	.395	.274	.336	.394
10m m/s (3)			1	.461	.750**	.869**	.731**	.731**	.770**	.642*	.707**	.744**	.428	.292	.335	.379
Momentum (kg.m/s) (4)				1	-.105	.589*	.382	.419	.438	.417	.441	.377	.818**	.165	.028	-.268
505 (5)					1	.543*	.603*	.450	.606*	.591*	.557*	.627*	-.090	.395	.546	.710**
Horizontal Jump (6)						1	.821**	.870**	.909**	.707**	.729**	.717**	.601*	.220	.478	.460
Right Horizontal (7)							1	.773**	.786**	.547*	.594*	.583*	.268	.340	.564*	.555*
Left Horizontal (8)								1	.748**	.428	.488	.553*	.380	.158	.371	.410
Vertical Jump (9)									1	.876**	.900**	.757**	.578*	.129	.754**	.727**
Right Vertical (10)										1	.922**	.808**	.637*	.181	.732**	.665*
Left Vertical (11)											1	.753**	.642*	.028	.693**	.619*
RSI (12)												1	.572*	.510	.385	.403
PPO (13)													1	-.059	.132	-.106
Leg Stiffness (14)														1	.014	.018
Squat 1RM (15)															1	.931**
Relative Strength (16)																1

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).
Performance measures are labelled as 1-16 for clear presentation of the data, duplicate data is omitted.

Deceleration Index

Table 4.20 presents the results of the 505 COD test, and 10m momentum in the form of a DI. From pre to post intervention 5 participants improved deceleration performance (M1, M2, M3, M6, M7), two participants reduced deceleration performance (M4, M5).

Table 4.20 Proposed Deceleration Index Results (male)

Participant	Pre 10m Momentum (kg.m/s)	Pre 505 (s)	Pre DI Score	Post 10m Momentum (kg.m/s)	Post 505 (s)	Post DI Score	Pre-Post DI Score Difference
M1	554.60	2.40	231.08	597.70	2.29	261.12	**30.04**
M2	444.09	2.49	178.35	454.59	2.48	183.67	**5.33**
M3	478.39	2.59	184.71	500.77	2.59	193.50	**8.79**
M4	439.33	2.17	202.45	448.24	2.22	201.91	-0.55
M5	466.29	2.14	217.89	470.52	2.19	215.34	-2.55
M6	453.26	2.41	188.08	471.10	2.39	197.03	**8.95**
M7	505.32	2.45	206.25	537.15	2.39	224.84	**18.59**

DI=Deceleration Index. **Bold** performances indicate an improvement in performance, the higher the score the better the performance

Chapter Five

Discussion

Deceleration is an important component of COD performance, and can be influenced through training. Practicing drills that are single leg, dynamic, reactive, eccentric and/or plyometric in nature, with correct posture and body positions can influence deceleration performance. Deceleration is a highly demanding and sometimes problematic movement, especially from maximal sprint velocities. Although there is not a significant breadth of research explaining the significance of this specific component and how to train this, the findings of this study aligned with the previous literature. Although 505 COD performance change appears minimal from pre to post intervention, when comparing individual results to SWC, and considering other performance measures and correlations, there were clear relationships that agree with the literature. A number of measures changed from pre to post intervention. 505 COD performance was improved or maintained across most participants while also improving in 10m speed, body mass and therefore momentum. Absolute and relative strength increased as well as jump performance increased in most participants, particularly during bilateral vertical jump and single leg jumping. The DI scale developed during this study could be a promising method for determining deceleration performance with further reliability and validity research using greater numbers of participants of different training experience. Positive results were reported in DI score from pre to post intervention in all participants in this study.

Change of Direction

Nine out of twelve participants improved or maintained performance in the 505 COD test (Table 4.3). Four of which exceeded the pooled results SWC value, and also reduced 505 deficit suggesting this was an improvement in performance for these four participants (Table 4.16) (Nimphius et al., 2016). Adherence could have affected the improvements observed in the 505 COD test, with participants attending 70 ± 8% of the sessions (Appendix I). When identifying specific participants in Appendix I, those with poorer session attendance may have produced poorer results than those who attended more frequently in the male group. The female group strength and conditioner who facilitated the implementation of the protocol reported an adherence of 100% for two sessions per week.

In addition, all participants increased body mass except one participant. When body mass is increased, more force and energy is required to generate the same sprint velocity observed in pre-testing. Not only is it more difficult to maintain or improve speed time with increased body mass, having increased momentum also increases breaking force requirements to decelerate, making it difficult to improve 505 COD time (Jalilvand et al., 2018). The participants in this study increased 10m speed (1.1 ± 2.6%), and 505 COD time (male=0.6 ± 2.4%, female=0.6 ± 2.3%), while also increasing body mass (male=2.8 ± 1.3%, female=1.5 ± 2.3%) during the 6 week training intervention. It is unknown why there were increases in body mass in both of these populations. Skinfolds were not obtained during this study due to limited resources so it is not known whether the increase in body mass has been lean body mass. Participants in the male group were unlikely to be participating in regular resistance training resulting in the reported increases in body mass due to hypertrophy. Training sessions were reported to be approximately 3 per week which 2-3 of these were consistently rugby skills or games. The questionnaire used to determine the number of training sessions included rugby games, trainings, strength training or other. The female group were participating in general strength training which could have resulted in increases in lean body mass, however it would be difficult to conclude whether this was the case over a 6 week period without skinfold measurements. Nonetheless, increased body mass will have increased momentum and resultant force application and absorption ability.

The ability to generate and control momentum has been identified as a crucial factor defining performance in rugby players more so than absolute sprint speed (Baker & Newton, 2008; Jalilvand et al., 2018). Momentum change reported for the male group increased significantly during the 6 week training intervention by 4 ± 2.5%. The female group were unable to participate in 10m speed testing due to time constraints, this would have been insightful for making a stronger conclusion with regard to momentum and increased breaking force requirements. The ability to apply more force per unit of body mass is crucial for performance in team sports like rugby (Delaney et al., 2016). Once a speed has been achieved it is valuable to increase body mass while maintaining speed to increase momentum (Delaney et al., 2016; Jalilvand et al., 2018). To understand whether force per unit of body mass has increased, a scale like a DI incorporating momentum would help strength and conditioning coaches to understand whether a period of training has elicited the desired response. When focusing on body mass and speed, it is vital to match the ability to decelerate with new performance capabilities to reduce the risk of injury and ensure the body is prepared for its own individual demands (Baker & Newton, 2008; Jalilvand et al., 2018; Joyce & Lewindon, 2014).

Jumping

Increased body mass also affects participants ability to maintain jumping performance with more force required to achieve the same jump height or distance (Jalilvand et al., 2018). Increases in body mass within and between players should be considered when looking at jump performance change (Jalilvand et al., 2018). Post intervention horizontal jump performance did not improve. Most participants either decreased or maintained performance during bilateral and right and left leg take-off. The performance deficit between legs became more balanced in several cases when looking at individual single leg jump results (Table 4.10). Two participants reduced asymmetry to 0% difference between legs. A number of the drills used in the warm-up protocol involved single leg movements, with optimal deceleration technique cues, emphasising strength and stability. This emphasis and intent with the drills may have improved single leg strength seen in horizontal and vertical jumping. Future research using a control group would better understand the effects this training intervention may have on this aspect of performance.

Unilateral vertical jump performance improved pre to post intervention. Improvements in single leg vertical jump performance were a notable finding of this study. Interestingly the left leg take-off showed significant improvement (Table 4.12). The left leg take-off improved beyond the SWC value (Table 4.12) for all participants, with most increasing both right leg and bilateral take-off as well. These results have also shown the commonly weaker left leg pre-intervention to perform closer to or better than the right leg in most cases with vertical jumping post intervention. This improvement showed a reduction in the asymmetry between single leg performances in all vertical jump performances (Table 4.10, Table 4.13), which is a commonly used indicator of lower limb strength for injury risk (Dos'Santos, Thomas, Jones, et al., 2018; Hart et al., 2014). Increased jump performance with increased body mass is indicative of increased power:mass ratio, which is crucial for rugby players (Baker & Newton, 2008; Jalilvand et al., 2018). The improvements seen with reducing asymmetry in jumping tasks could be an important aspect of improving COD performance as jump task performance has had high correlation to COD performance in this study (Table 4.19).

Lower Body Strength

Strength training with the male group was self-prescribed, the participants were involved in an average total of 3.3 ±1.5 training sessions/games per week (Table 4.1). During the intervention the male participants attended two team trainings and one game per week, most participants would not be taking part in regular resistance training according to the information provided. However, post intervention, there were improvements in relative and absolute strength with 1RM squat greater than the SWC value (Table 4.6, Table 4.7). This improved strength could be linked to the increases in jump performance, speed and 505 COD time observed. It is difficult to determine whether the training intervention had a direct effect on the increase in strength measures used in this study. Due to the nature of the drills and strength demands required, especially during single leg drills, there could be some effect on coordination and body awareness that could possibly transfer to ability in the squat or other loaded movements. There could have also been some strength stimulus provided by the deceleration drills and rapid deceleration efforts, as seen with the high correlation between relative strength (r=0.710) and 1RM squat (r=0.546) with the 505 COD test found in this study. It has also been reported that there is a strong relationship between eccentric strength and the deceleration component of the 505 COD test which could have increased participant strength during the duration of this study (Jones et al., 2017). Without explicit detail of any extra training that was not disclosed by the male participants during the study, it would be difficult to know to what extent the training intervention had on the increased strength observed.

Correlations

When pre and post intervention data is combined, there are up to 14 participants in the performance measures used, where more reliable correlations to 505 COD performance are able to be analysed. There were strong relationships between the performance measures and 505 COD test. From this pooled correlation data, 10m (r=0.768) and 10m m/s (r=0.750) were very highly correlated to 505 COD performance. This agrees with Baker (2008), Sheppard et al. (2014) and Green et al. (2011), who showed that straight line sprinting, along with other lower body strength qualities influence the ability to perform COD effectively. Body mass (*r*=-0.553) had a high negative correlation to 505 COD performance, reinforcing the literature findings that the lower the body mass, the more likely a good performance in the 505 COD test can occur (Baker & Newton, 2008; Spiteri et al., 2015). Delaney et al. (2016) emphasised that once a desired body composition is achieved, the ability to apply more force per unit of body mass is a determining factor and is highly correlated to superior COD performance. This was seen in the current results, where participants increased speed, and increased body mass, therefore producing more power per unit of body mass, and also increasing demands for controlling momentum with regard to strength, technique and injury protection mechanisms (Baker & Newton, 2008; Dos'Santos, Thomas, Jones, et al., 2018; Harper et al., 2018; Jones et al., 2017; Tominaga et al., 2016).

Relative strength (*r*=0.710) and 1RM squat (*r*=0.546) was very highly correlated to 505 COD performance. An individual needs to be able to tolerate enough force specific to their own individual demands (Young, 2006). When training athletes and setting bench marks, this relationship can give more support when setting strength targets for individuals and understanding what needs to be improved with insight from deterministic models (Joyce & Lewindon, 2014; Watts, 2015; Young, 2006). Relative strength is especially important with regard to the momentum an athlete is likely to generate (Baker & Newton, 2008; Jones et al., 2017). Young (2006), and Watts (2015) emphasised the importance of relative strength and increasing this capacity in order to maintain and improve COD ability while increasing speed, body composition and other performance variables, or complexity of COD tasks to ensure appropriate control of the body (Baker & Newton, 2008). Eccentric strength has a very strong relationship with the ability to decelerate, especially during cutting and side stepping (Baker & Newton, 2008; Colby et al., 2000; Green et al., 2011; Jones et al., 2017; Shimokochi et al., 2013). It would have been insightful to understand the changes in eccentric strength as a result of this study as there was no regular strength training in the male group that would account for the increase in strength across participants.

Watts (2015) also recommended targeting improvement of maximal relative vertical strength, with emphasis on hip and knee extension and flexion tasks like the squat should be a primary focus for strength training to improve ability in COD tasks. Tominaga et al. (2016) and Harper et al. (2018) also emphasised the importance of knee extensor strength while increasing load at the knee, applying breaking forces at increasing sprint velocities. Improving the ability to load the knee will result in faster time or distance to decelerate and reduce injury (Baker & Newton, 2008; Graham-Smith et al., 2018; Harper et al., 2018; Tominaga et al., 2016). Increasing strength capacity across all contraction types, especially eccentric contraction both bilaterally and unilaterally will also improve COD ability (Gleason et al., 2015; Hart et al., 2014; Hewit et al., 2011; Kovacs et al., 2008; Sheppard et al., 2014; Spiteri et al., 2015). Superior performers during the 505 COD test were superior in vertical strength tasks, measured by vertical force during an eccentric squat, 1RM squat, relative strength, and vertical jumping tasks (Spiteri et al., 2015), agreeing with the results of this thesis. The drills used in this study reflect the contraction types and movements described as important for superior performance in COD tasks (Baker & Newton, 2008; Gleason et al., 2015; Harper et al., 2018; Kovacs et al., 2008; Sheppard et al., 2014; Tominaga et al., 2016; Watts, 2015).

Bilateral horizontal jump (r=0.543) and right leg horizontal jump (r=0.603), bilateral vertical jump (r=0.606), right leg vertical jump (r=0.591) left leg vertical jump (r=0.557), and RSI (r=0.627) had a high correlation to 505 COD performance. Interestingly, left leg horizontal jumping was only moderately correlated to 505 COD performance (r=0.450). This finding could be related to the dominance of one leg for planting and/or pushing off from during a COD (Dos'Santos, Thomas, Jones, et al., 2018; Hart et al., 2014; Spiteri et al., 2015; Thomas et al., 2018). Most participants in this group were possibly right leg dominant for horizontal strength and also may favour this leg during COD tasks more so than the left leg. Other research has shown that single leg countermovement jump (CMJ) height (vertical jump tests used in this study were performed as CMJ) has been found to have moderate correlations to 505 COD, similar to what was observed in this study (Thomas et al., 2018). Thomas et al. (2018) showed that the superior limb for CMJ was moderately related to the dominant leg used for planting during COD. Bilateral and unilateral horizontal jumping had previously been found to have moderate to large correlations to 505 COD (Thomas et al., 2018). Thomas et al. (2018) suggested that this correlation was due to the similar force absorption qualities horizontal jumping and deceleration for COD share. This is interesting to note for injury risk for returning to play and improving performance by introducing effective tasks. For athletes to become more versatile across both legs for COD movements, practicing the movement, and performing horizontal single leg strength or plyometric tasks could increase competency for using either leg to decelerate and change direction (Baker & Newton, 2008; Joyce & Lewindon, 2014; Kovacs et al., 2008; Nimphius, 2014; Ranson & Joyce, 2014). Dos'Santos et al., (2018) recommend placing high importance on eccentric strength bilaterally and unilaterally to optimise deceleration performance and reduce risk of injury by possessing adequate strength to absorb an individuals own breaking force demands. This recommendation reflects the drills used in the training intervention of this study and could elicit the described desired adaptations.

The high correlation between horizontal and vertical jumping, and relative strength to the 505 COD test confirms the previous findings that lower body strength is important for COD performance (Baker & Newton, 2008; Dalen et al., 2016; Delaney et al., 2016; Dos'Santos, Thomas, Jones, et al., 2018; Gabbett et al., 2008; Griffith, 2005; Harper et al., 2018; Hart et al., 2014; Hewit et al., 2011; Jalilvand et al., 2018; Joyce & Lewindon, 2014; Keiner et al., 2014; Lakomy & Haydon, 2004; Spiteri et al., 2015; Thomas et al., 2018; Tominaga et al., 2016; Watts, 2015; Young, 2006). This correlation is also helpful for teams that may not have access to a weight room to perform maximal or submaximal strength testing. Vertical and horizontal jumps provide an adequate indication of lower body strength and power when wanting insights into COD performance. This is supported by the literature and by the high or very high correlations between vertical jumping tests, and moderate and high correlations with horizontal jumping tests and relative and 1RM strength in this study. It is important to monitor unilateral lower body strength and function, as well as emphasising intent on both dominant and non-dominant deceleration drill and strength repetitions (Bishop et al., 2016; Lockie et al., 2015; Lockie et al., 2013; Tominaga et al., 2016).

The RSI derived from the bounce drop jump test, was also highly correlated to 505 COD performance and did not improve post intervention. Although RSI did not improve, this can be accounted for with the increase in body mass post intervention making this measure difficult to improve or maintain. The calculation for RSI used in this study does not factor in the body mass of the athlete, changes in body mass have not been considered with this measure. This high correlation, confirms the previous findings with regard to eccentric strength and utilisation of the stretch shorten cycle being important components of superior COD performance (Hewit et al., 2011; Kovacs et al., 2008; Young, 2006). It would have been insightful to incorporate video analysis with the bounce drop jump test for assessing landing mechanics. This additional layer of analysis could have shown whether or not the superior performers also had a superior landing and take-off movement strategy during this test. Unfortunately, this was not included in the data collection, but would have provided some useful analysis and should be considered for future research.

From the results of this study, considering the small subject pool and adherence, it was shown that implementing deceleration drills and rapid deceleration repetitions can have some influence 505 COD performance and should be implemented into regular training sessions. Single leg performance during vertical jumping tasks was improved post training intervention, which is often a measure used to determine injury risk and lower body strength (Dos'Santos, Thomas, Jones, et al., 2018; Harper et al., 2018; Thomas et al., 2018). This study in agreement with the literature, showed that there could be a relationship between single leg horizontal jump performance and 505 COD performance, which could be attributed to a dominant leg being used to execute COD tasks. If there is an obvious dominant leg it will serve the athlete well to implement more single leg strength or plyometric tasks. Practicing the movement off both legs regularly may help to ensure the athlete is improving performance to become more versatile off both legs, as well as reducing potential for injury while using a non-dominant side.

Deceleration Index

From this study it was hoped that a DI to assess deceleration performance could be proposed. Due to the limitations of the study, the intended measures to develop this DI were not accessible. However, a minimally resourced index/scale of performance has been developed and will be discussed in this section. The 505 test is specific for measuring rapid deceleration as an already existing COD performance measure. It features a high velocity sprint entry to decelerate with high breaking force requirements, with the intent to change direction immediately (Nimphius, 2014; Nimphius et al., 2018; Nimphius et al., 2016). The 505 deficit proposed by Nimphius et al. (2016), factors in 10m speed time and 505 time to produce a deficit time. This deficit suggests whether or not COD ability needs to be improved, or has improved after a period of training. Table 4.16 examines the 505 deficit produced by participants in this study as per Nimphius et al. (2016). This second layer of assessment to the total time to complete the COD task provides valuable and valid insight to performance, however this neglects the concept of momentum and changing body mass during periods of training.

If teams are able to access body mass scales and speed timing lights, 10m, and 505 COD times can be obtained. Momentum during the 0-10m build up to the 505 or 10m max speed effort could be calculated. This momentum value can then be divided by the time taken to complete the 505 COD test. Table 5.1 is a proposed DI scale based on the participants of this study, which can be applied to all sporting populations who use this test, or in application of other tests with high momentum and breaking force requirements. This calculation produces an output (Table 4.20) that could be used to compare deceleration performance using the DI scale proposed below. As the 505 COD test also incorporates the re-acceleration part of the test, a more specific way of assessing the ability to decelerate would be for the athlete to sprint 10m and have 3-5m to decelerate onto a force platform or other lab based assessment like video analysis. Time taken for the athlete to stop could then be integrated with momentum and number of steps or distance to stop to create a more sophisticated scale of performance.

Table 5.1 Potential Deceleration Index Scale

DI SCALE	
>300	Excellent
200-300	Good
100-200	Average
<100	Poor

DI=Deceleration Index

From this scale, the larger the number in the DI score column, the better the performance (Table 4.20). The participant (M2) with the rating 183.67 post intervention only had to slow a momentum of 454.59kg.m/s with a time of 2.48s (Table 4.20), which is one of the poorer times in the data set, and one of the lesser momentums of the data set post intervention. Whereas the best performance is noted by the participant (M1) who had a momentum to slow of 597.70kg.m/s and 505 COD time of 2.29s, producing a rating of 261.12 post intervention (Table 4.20), which is the highest score post intervention. This accurately depicts who had the greatest momentum demands to stop, and who stopped this in the most effective time from the data produced in this study. A scale of 0-300 could be useful to categorise performance to compare large groups. This scale can also provide understanding if deceleration should be worked on for the individual, indicated by the change in performance after a period of training. As mentioned earlier, it would be ideal to have access to force platforms where only the deceleration component is assessed, but for a field based assessment with limited resources this could provide insight into how to rate performance across a team. This also builds on or can be used with the 505 deficit proposed by Nimphius et al. (2016) to incorporate body mass into the assessment of COD performance.

Deceleration Zone Distance

During the pilot testing of this study it was decided that 3m was sufficient for initial deceleration zones from shorter sprints of 10-20m, especially for introductory level sessions if implementing this into training. The distance to stop could be reduced as athletes become more proficient, or have the athlete decelerate using less steps i.e. reducing from five steps to come to a stop, to three steps within the deceleration zone. As expected during planning of the warm-up protocol, after the first week of practicing the drills, the participants were able to decelerate to a stop with less steps than the initial session. Most participants reducing from five steps to three steps when becoming familiar with the movement and improving technique. The number of steps taken to decelerate were not recorded or included in analysis, this would be useful in future research to capture to understand performance improvements. Visual improvements while observing participant movement during the intervention sessions showed increased competency through reduced steps to stop. Although this was not used in the training intervention, for distances further than 30m it was decided that it would be appropriate to use 4-5m breaking zones. These zones were based on previous research by Lakomy and Haydon (2004). This would also depend on the speed of the athlete to determine the distance required to stop if sprinting maximally. A slower athlete who may not necessarily reach top speed, or hold their top speed for the entire distance, may only require a short distance, and a faster athlete may require further to decelerate. It would be useful to have a reliable calculation based on distance specific velocities to determine individual deceleration zone prescription. This would have to incorporate momentum, distance covered, and steps taken, with shortest and furthest expected distance to stop this momentum. A more sophisticated calculation could integrate force platform breaking force data and number of strides to determine this distance, however this was beyond the scope of this study and could be difficult to implement from a practical standpoint when working with teams who do not have access to equipment. A recent study has investigated this concept with lab based assessment of deceleration from maximal acceleration (Graham-Smith et al., 2018). It was suggested that for a sprint of 2m in duration, 3m would be required to decelerate momentum, a 10m sprint would require 7.4m to decelerate (Graham-Smith et al., 2018). During the training intervention we found no issues with technique and intent to sprint maximally with the 3m deceleration zone used. It may be that in reality, less distance is required to decelerate from maximal speed when ability is superior. Alternatively, participants in our study may not have been reaching maximal speed while performing 10m and 20m sprints, especially those who were not as fast as others in the study, requiring less distance to stop during the training intervention used in this study.

Limitations

There were a number of limitations that affected this study. Having a small sample size was one of the obvious limitations. This was due to participant availability to attend the scheduled testing days. Even though they had participated in the 6 week training intervention, some participants only attended one of the testing sessions. This was likely due to the pre-intervention testing session occurring during early pre-season training, where players were not fully committed to attending team trainings at that point in time. This dramatically reduced the data produced at the end of data collection. There were an additional twenty four participants who did participate in the training intervention whose data sets were not complete and could not be used in the results of this study. This additional data could have improved the strength of the data and the ability to use more comprehensive analysis. Increased participation could have also provided the opportunity to have a control group and intervention group. This could have strengthened the findings further by determining the effect that the absence of the protocol had on participants with regard to 505 COD performance.

To accommodate the teams involved in the training intervention, the duration of each session needed to fit within the time allocation offered by the coaches. Because of this, the training intervention was reduced in duration and volume in the form of a warm-up protocol. If the training intervention was not limited by time, the participants could have produced stronger results if more drills and rapid deceleration repetitions from different distances and speeds were able to be incorporated with full rest between bouts. However, as a warm-up protocol, the intervention did provide worthwhile performance changes.

Participant intent and adherence was also something that could have impacted the participation in this study for those who did produce full data sets. A register of session attendance was recorded with only those who were included in the results analysis reported (Appendix I). Even with this small set of data it was shown that there could have been some further improvement if the attendance to sessions was higher for some individuals. Intent and intensity with drills would affect the ability to adapt to the training intervention. If rapid decelerations and drills were being performed at a low intensity participants will not have been able to experience the training at an intended intensity for the desired adaptations to occur. All participants were instructed to perform sprints maximally, however ability and familiarity with tasks could have affected the participants ability to perform maximally.

The number of measures able to be used was also limited by the time available while working with participants. The female group were only able to take part in the 505 COD test and provide body mass data. With more data sets and more measures, this could have possibly provided stronger information to correlate different lower body characteristics or qualities with COD performance.

It was also hoped that specific deceleration testing could be performed on force platforms, coupled with video analysis. This could have been powerful for understanding whether or not movement strategies had changed significantly from pre to post intervention. From a qualitative perspective there was an improvement in coordination and intent while executing the drills and deceleration repetitions at each session. It was hoped that breaking force data, coupled with video analysis, would aid in understanding whether the training intervention would elicit the following improvements in the components of deceleration performance: larger GRF, lesser angle of GRF vector, lower height of COM during deceleration, improved dynamic balance and dissipation of forces, fewer strides with greater breaking force application and/or longer contacts to apply breaking force. The ability to analyse some, or all of these mentioned components would have been extremely insightful with the small number or participants that were able to be used for this study.

Recommendations for Future Research

It is often the case that athletes have performance differences between limbs, especially when favouring a dominant leg for breaking and turning or accelerating (Lockie et al., 2013). It is important to use a COD or stopping task that alternates legs to make sure significant differences do not occur between legs (Lockie et al., 2013). This information and monitoring not only creates a robust athlete who can adjust a movement strategy to utilise either leg but also provides information around preventing injury or to have a target for the athlete to return to post injury. It would be valuable to investigate the kinetics and kinematics of superior movement strategies for deceleration to a stop or reactive movement using video analysis and force plates to develop a framework or competency model to utilise for prescription in a strength and conditioning program.

It would be interesting to also investigate the relationship between fatigue and deceleration; considering the implications fatigue has on deceleration and/or the incidence of fatigue as a result of deceleration. This could have an impact on field performance, as well as ability to be successful in aerobic tests such as the Yo-Yo test. Video analysis would also be a valuable resource to track the movement competency of athletes with introducing new drills and movement, coupled with force platform analysis to understand breaking force improvements. In future, the development of a user-friendly field based evaluation of deceleration performance in the form of competency levels or tiers could be significant for reducing risk of injury and improving COD performance, and assist in programming movements with respect to an individual’s competency.

Another interesting idea provoked by this study is that of the dominant or non-dominant leg selection for decelerating and resultant set up position for subsequent movement. The leg that is placed forward at the turn will have the least contact with the ground, while the leg which is under the COM has the most contact with the ground and most eccentric tension. This leg under the COM is automatically going to be the leg that pushes off the ground first as the other leg is in flight to follow through with the first ground contact. It would be interesting to understand whether the selection of final plant leg is more related to the ability to slow momentum effectively, or to set up for a more effective re-acceleration. Thomas et al. (2018) found that it was unclear how unilateral strength qualities specifically relate to the ability to change direction. However they also posed the question into the relationship of unilateral and bilateral strength with regard to preparatory steps while changing direction (Thomas et al., 2018). It could be expected that the role of bilateral strength is also vitally important while decelerating as there is often two feet in contact with the ground to absorb force more effectively. Dos’Santos et al. (2018) also discussed this with regard to the preparedness of the lower body to accept high load and breaking forces while decelerating. Not only the plant leg, but the steps taken in preparation to stop and change direction are vital in optimising COD performance, and play a role in reducing risk of injury during such demanding movements (Dos'Santos, Thomas, Comfort, et al., 2018).

Practical Applications

The results of this study suggest that the implementation of deceleration training drills two times per week for six weeks could have positive benefits for COD time, strength and single leg vertical jump performance. Specifically when looking at the data at the individual level, increases in body mass and sprint speed from pre to post intervention did not reduce performance in COD as would be expected. This finding could be attributed to the introduction of deceleration drills. These results indicate that the inclusion of deceleration specific drills and skills from varying velocities, especially high speed sprinting could be valuable to have in the training program while improving other areas of performance i.e. body mass, speed, strength. Skills should be introduced as basic tasks, and increase complexity as the athlete becomes more familiar and refines this ability. Drills should reflect the individual as well as the sport position demands and work ons. From the findings of this study, deceleration training can be incorporated into a warm-up protocol for ease of inclusion and repetitive exposure to the drills to increase competency and tolerance. Deceleration training is a simple and specific focus, with cues and intent of the exercises focusing applying breaking forces and body position. This focus can also be added into the end of any speed task, which does not require extra time allocation, but provide meaningful adaptation for performance and injury prevention.

Conclusion

The findings of this thesis suggest that more research needs to be done on how to train the deceleration component of COD as it has been found to be crucial in superior performance and the main culprit of injury during this movement. The training intervention used in this study improved 505 COD performance, as well as lower body strength qualities such as absolute and relative strength, as well as vertical jumping tasks, namely reducing asymmetry between legs. It is regularly reported that reducing asymmetry between legs during strength and other single leg tasks is of high importance for reducing injury and increasing versatility of non-dominant sides on the field. When using the 505 deficit proposed by Nimphius et al. (2016), the improvements seen in 505 performance were valid for the individuals in this study. Improvements in performance were further strengthened by the development and application of the DI scale suggested in this thesis. When applying the DI scale to pre and post momentum and 505 performance, it was shown that all participants in this study improved their ability to decelerate. Although absolute time to complete the 505 test may not have improved, coupled with both increases in speed and increases in body mass, the ability to decelerate individual momentum requirements improved pre to post intervention. The intervention drills focused on single leg, plyometric, reactive, stability and high breaking force demands, as well as the emphasis on maximal sprinting and rapid deceleration with appropriate progressions. Focusing on technique and skill with this component of fitness can easily be incorporated into team trainings as a regular stimuli that will elicit performance and injury prevention benefits.

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Appendices

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Appendix H: Deceleration training intervention video link: https://youtu.be/0xtj03yAn44

Appendix I: Participant attendance record

Appendix A: Ethics Approval

AUTEC Secretariat

Auckland University of Technology
D-88, WU406 Level 4 WU Building City Campus
T: +64 9 921 9999 ext. 8316
E: ethics@aut.ac.nz
www.aut.ac.nz/researchethics

31 July 2017

Nic Gill
Faculty of Health and Environmental Sciences

Dear Nic

Re Ethics Application: **17/233 Does the implementation of deceleration training optimise change of direction performance in rugby players?**

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 31 July 2020.

Standard Conditions of Approval

1. A progress report is due annually on the anniversary of the approval date, using form EA2, which is available online through http://www.aut.ac.nz/researchethics.
2. A final report is due at the expiration of the approval period, or, upon completion of project, using form EA3, which is available online through http://www.aut.ac.nz/researchethics.
3. Any amendments to the project must be approved by AUTEC prior to being implemented. Amendments can be requested using the EA2 form: http://www.aut.ac.nz/researchethics.
4. Any serious or unexpected adverse events must be reported to AUTEC Secretariat as a matter of priority.
5. 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.

Non-Standard Conditions of Approval

1. Suggest 50+ is rephrased as 'we are seeking about 50'

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

AUTEC grants ethical approval only. If you require management approval for access for your research from another institution or organisation then you are responsible for obtaining it. You are reminded that 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.

For any enquiries, please contact ethics@aut.ac.nz

Yours sincerely,

K O'Connor

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

Cc: hayley.gilchrist@gmail.com; dan.smart@hpsnz.org.nz

Appendix B: Participant information sheet

Participant Information Sheet

Date information sheet produced: 30 May 2017

Project Title: Does the implementation of deceleration training optimise change of direction performance in rugby players?

Invitation:

My name is Hayley Gilchrist, I am a Masters candidate enrolled at the Sports Performance Research Institute New Zealand (SPRINZ), at Auckland University of Technology (AUT). We are conducting a study to investigate whether targeted deceleration training will improve change of direction performance in rugby players. Your participation in this research would be highly valued, this study is entirely voluntary and you may withdraw your participation in the study at any time prior to the completion of data collection.

Research Aims:

The aim of this research is to understand deceleration movement patterns and specific deceleration training to improve change of direction performance. The research is broken down into two parts. For part one of the research we are going to collect data to determine a movement model with the average movement ability at different levels of play. This will be used to identify good and/or poor/risky movement strategies, so that coaches and players can understand what is needed for improving performance and reducing risk of injury. There will be a number of performance data collected to investigate movement requirements for change of direction.

Identifying the differences between levels of play and/or gender allows trainers to develop training and skill programs to align with the game demands of the next level of play. This will provide an understanding of what players should be able to do physically at each level to provide direction for training progressions.

Part two of the research will be the training intervention. The training intervention component will involve a 6 week period of normal training and exercise. There will be a testing session at the start and the end of the 6 weeks to see what changes happen with your normal training.

The training intervention will involve 2 deceleration training sessions each week for 6 weeks, these will be no longer than 1 and a half hours long. Other training sessions may be continued as normal during this time. The deceleration training sessions will focus on learning safe and effective deceleration movement strategy drills, and near maximal sprints with rapid decelerations. Final follow up data collection will let us know how each athlete has changed over the 6-week training intervention across the chosen tests.

How was I selected to be invited to participate in this study?

We are seeking 50 women's rugby players of at least 12 months playing experience, from different levels of play to participate in this study. We need to see how different levels of play affect the movement strategy used during deceleration and change of direction, and what good and/or poor/risky movement strategies look like at each level. From this we will create a deceleration competency model for trainers to use with teams to best prepare players for the level of play currently participating in, and the next level of play expected to be involved in.

We need players who have been involved in rugby for at least 12 months, and have been injury free or cleared to play by a physio for at least 6 months prior to the commencement of this study.

How was I Identified?

Your union, coach, team, school or parent have expressed interest in having you participate in this study as you may fit the criteria to take part in this study and/or have stood out as someone who would be interested in taking part.

What benefits will you gain from participating in this study?

You have the opportunity to have three performance testing sessions and a 6-week training program to help improve performance and reduce injury in relation to deceleration and change of direction performance. As a participant, you are able to receive a copy of your individual performance results and a copy of the research findings that you were involved in. This information will be helpful for your future training programmes so that you can best understand your areas of strength and areas you may need to work on. If you indicate on the consent form, your coach can also have this information made available so that they can create the best plan to help you be successful.

What will happen during the research?

You will be required to take part in a performance testing session at the beginning of the study, this will be our initial baseline testing. The tests of interest are related to deceleration and change of direction performance; we will track the changes in these tests through the study with two more testing sessions 6 weeks apart. Approximately 30 hours of your time will be required to participate in this study, this includes 3x performance testing sessions, and 2x 1.5 hour training sessions per week for 6 weeks.

The performance tests of interest are:

- Lower body strength – 1-5 repetition maximum squat performance or prediction,
- Reactive strength – drop jump,
- Lower body power – horizontal and vertical jump,
- Acceleration – 5m, 10m, 20m, 40m,
- Change of direction – 505,
- Deceleration – rapid deceleration protocol,
- Body composition - limb length, height, body fat percentage, Movement competency.

The second testing session will be 6 weeks after the baseline testing, you will continue to be involved in normal exercise and training sessions during this 6-week period. This will allow us to see what changes may be expected from your normal training.

Following this second testing session you will participate in the 6-week training intervention. This will involve a commitment to attending two training sessions each week for 6 weeks, these sessions will focus on learning the deceleration skill through drills, and executing rapid decelerations from short near maximal sprint efforts. At the end of the 6-weeks you will undergo a final testing session to see what changes have occurred as a result of the deceleration training. We will then take this information away and write up conclusions about this training intervention to make recommendations for training focuses to improve performance and reduce injury related to change of direction and deceleration.

What are the discomforts or risks involved in participating in this study?

You should not experience discomforts or risks during this study that are different to what you already experience during normal training and exercise. You may experience muscle soreness following testing sessions as these are maximal tests, which would be similar to muscle soreness you have experienced in the past after a hard training session, or when you have not trained for a while, i.e. first training back for the season.

Appendix C: Parent's information sheet

Parent/caregiver Information Sheet

AUT
TE WĀNANGA ARONUI O TĀMAKI MAKAU RAU

Date information sheet produced: 30 May 2017

Project Title: Does the implementation of deceleration training optimise change of direction performance in rugby players?

Invitation:

My name is Hayley Gilchrist, I am a Masters candidate enrolled at the Sports Performance Research Institute New Zealand (SPRINZ), at Auckland University of Technology (AUT). We are conducting a study to investigate whether targeted deceleration training will improve change of direction performance in rugby players. Your child's participation in this research would be highly valued, this study is entirely voluntary and you or your child may withdraw participation in the study at any time prior to the completion of data collection.

Research Aims:

The aim of this research is to understand deceleration movement patterns and specific deceleration training to improve change of direction performance. The research is broken down into two parts. For part one of the research we are going to collect data to determine a movement model with the average movement ability at different levels of play. This will be used to identify good and/or poor/risky movement strategies, so that coaches and players can understand what is needed for improving performance and reducing risk of injury. There will be a number of performance data collected to investigate movement requirements for change of direction.

Identifying the differences between levels of play and/or gender allows trainers to develop training and skill programs to align with the game demands of the next level of play. This will provide an understanding of what players should be able to do physically at each level to provide direction for training progressions.

Part two of the research will be the training intervention. The training intervention component will involve a 6-week period of normal training and exercise. There will be a testing session at the start and the end of the 6 weeks to see what changes happen with your normal training.

The training intervention will involve 2 deceleration training sessions each week for 6 weeks, these will be no longer than 1 and a half hours long. Other training sessions may be continued as normal during this time. The deceleration training sessions will focus on learning safe and effective deceleration movement strategy drills, and near maximal sprints with rapid decelerations. Final follow up data collection will let us know how each athlete has changed over the 6-week training intervention across the chosen tests.

How was my child selected to be invited to participate in this study?

We are seeking 50 women's rugby players of at least 12 months playing experience, from different levels of play to participate in this study. We need to see how different levels of play affect the movement strategy used during deceleration and change of direction, and what good and/or poor/risky movement strategies look like at each level. From this we will create a deceleration competency model for trainers to use with teams to best prepare players for the level of play currently participating in, and the next level of play expected to be involved in.

We need players who have been involved in rugby for at least 12 months, and have been injury free or cleared to play by a physio for at least 6 months prior to the commencement of this study.

How was my child Identified?

Your child's union, coach, team, or school have expressed interest in having your child participate in this study as they may fit the criteria to take part in this study and/or have stood out as someone who would be interested in taking part.

What benefits will your child gain from participating in this study?

Your child has the opportunity to have three performance testing sessions and a 6-week training program to help improve performance and reduce injury in relation to deceleration and change of direction performance. As a participant, your child is able to receive a copy of their individual performance results and a copy of the research findings that they were involved in. This information will be helpful for future training programmes so that your child can best understand their areas of strength and areas they need to work on. If you indicate on the consent form, your child's coach can also have this information made available so that they can create the best plan to help your child be successful.

What will happen during the research?

Your child will be required to take part in a performance testing session at the beginning of the study, this will be our initial baseline testing. The tests of interest are related to deceleration and change of direction performance; we will track the changes in these tests through the study with two more testing sessions 6 weeks apart. Approximately 30 hours of your child's time will be required to participate in this study, this includes 3x performance testing sessions, and 2x 1.5-hour training sessions per week for 6 weeks.

The performance tests of interest are:

- Lower body strength – 1-5 repetition maximum squat performance or prediction,
- Reactive strength – drop jump,
- Lower body power – horizontal and vertical jump,
- Acceleration – 5m, 10m, 20m, 40m,
- Change of direction – 505,
- Deceleration – rapid deceleration protocol,
- Body composition - limb length, height, body fat percentage, Movement competency.

The second testing session will be 6 weeks after the baseline testing, your child will continue to be involved in normal exercise and training sessions during this 6-week period. This will allow us to see what changes may be expected from their normal training.

Following this second testing session your child will participate in the 6-week training intervention. This will involve a commitment to attending two training sessions each week for 6 weeks, these sessions will focus on learning the deceleration skill through drills, and executing rapid decelerations from short near maximal sprint efforts. At the end of the 6-weeks they will undergo a final testing session to see what changes have occurred as a result of the deceleration training. We will then take this information away and write up conclusions about this training intervention to make recommendations for training focuses to improve performance and reduce injury related to change of direction and deceleration.

What are the discomforts or risks involved in participating in this study?

Your child should not experience discomforts or risks during this study that are different to what they already experience during normal training and exercise. Your child may experience muscle soreness following testing sessions as these are maximal tests, which would be similar to muscle soreness they have experienced in the past after a hard training session, or when they have not trained for a while, i.e. first training back for the season.

Appendix D: Participant consent form

Participant Consent Form

Project title: ***Does the implementation of deceleration training optimise change of direction performance in rugby players?***

Project Supervisor: ***Dr Nicholas Gill, Dr Daniel Smart***

Researcher: ***Hayley Gilchrist***

○ I have read and understood the information provided about this research project in the Information Sheet dated 30 May 2017.

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

○ 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 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 not suffering from heart disease, high blood pressure, any respiratory condition (mild asthma excluded), any illness or injury that impairs my physical performance.

I agree to take part in this research *performance testing and data collection.* **Yes/No** *(please circle)*

I agree to take part in the *training intervention* **Yes/No** *(please circle)*

I agree that my test results may be provided to my sports coach, manager or doctor in de-identified form if requested. **Yes/No** *(please circle)*

I agree to my test results being stored in de-identified form (without my name or personal details attached) in the SPRINZ research database and potentially used in future research studies of a similar nature: **Yes/No** *(please circle)*

I wish to receive a copy of the research at completion **Yes/No** *(please circle)*

I wish to receive a copy of my individual results summary at completion of the research **Yes/No** *(please circle)*

Participant signature: ....

Participant name: ....

Participant Contact Details (if appropriate): ....

Date:..................... ....

Approved by the Auckland University of Technology Ethics Committee Ethics Application 17/233, approved 31/07/2017

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

Appendix E: Parent’s consent form

Parent/Caregiver Consent Form

Project title: ***Does the implementation of deceleration training optimise change of direction performance in rugby players?***

Project Supervisor: ***Dr Nicholas Gill, Dr Daniel Smart***

Researcher: ***Hayley Gilchrist***

○ I have read and understood the information provided about this research project in the Information Sheet dated 30 May 2017.

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

○ I understand that taking part in this study is voluntary and that the participant may withdraw from the study at any time without being disadvantaged in any way.

○ 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.

○ The participant is not suffering from heart disease, high blood pressure, any respiratory condition (mild asthma excluded), any illness or injury that impairs physical performance.

I agree to my child taking part in this research *performance testing and data collection.* **Yes/No** *(please circle)*

I agree to my child taking part in the *training intervention* **Yes/No** *(please circle)*

I agree that my child’s test results may be provided to the sports coach, manager or doctor in de-identified form if requested. **Yes/No** *(please circle)*

I agree to these test results being stored in de-identified form (without name or personal details attached) in the SPRINZ research database and potentially used in future research studies of a similar nature: **Yes/No** *(please circle)*

I wish to receive a copy of the research at completion **Yes/No** *(please circle)*

I wish to receive a copy of my child’s individual results summary at completion of the research **Yes/No** *(please circle)*

Parent/caregiver signature: ....

Parent/caregiver name: ....

Participant name: ....

Participant Contact Details (if appropriate): ....

Date:.................... ....

Approved by the Auckland University of Technology Ethics Committee: Ethics Application 17/233, approved 31/07/2017

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

Appendix F: Pre-participation questionnaire

Pre Participation Questionnaire

AUT
TE WĀNANGA ARONUI O TĀMAKI MAKAU RAU

Please complete this questionnaire once you have returned your consent to participate in this study

Name:______________________________ DOB:______/______/__________Age:_____________

Team: ______________________________ Email:_____________________________________

Injury History:

Have you suffered from significant injury that limits your ability to participate in exercise (please circle)

YES/NO

If Yes, have you been cleared to resume normal physical activity and sport training for at least the last 6 months

YES/NO

Please provide detail about recent injury below:

____

____

Rugby Participation History:

Which ruby code(s) are you usually involved in? (please circle)

15s 7s touch league

What level of rugby are you involved in currently? (please circle)

High school Club Provincial National

What is the highest level of rugby you have been involved in? (please circle)

High school Club Provincial National

How long have you played rugby?

Years__________ and/or Months _____________

What level of rugby do you hope to be involved in in the future?

____

____

Proceed to page 2

AUT

TE WĀNANGA ARONUI O TĀMAKI MAKAU RAU

How many days a week do you participate in rugby and or strength and conditioning training/games?

Sunday Monday Tuesday Wednesday

Thursday Friday Saturday

What do these trainings usually consist of?

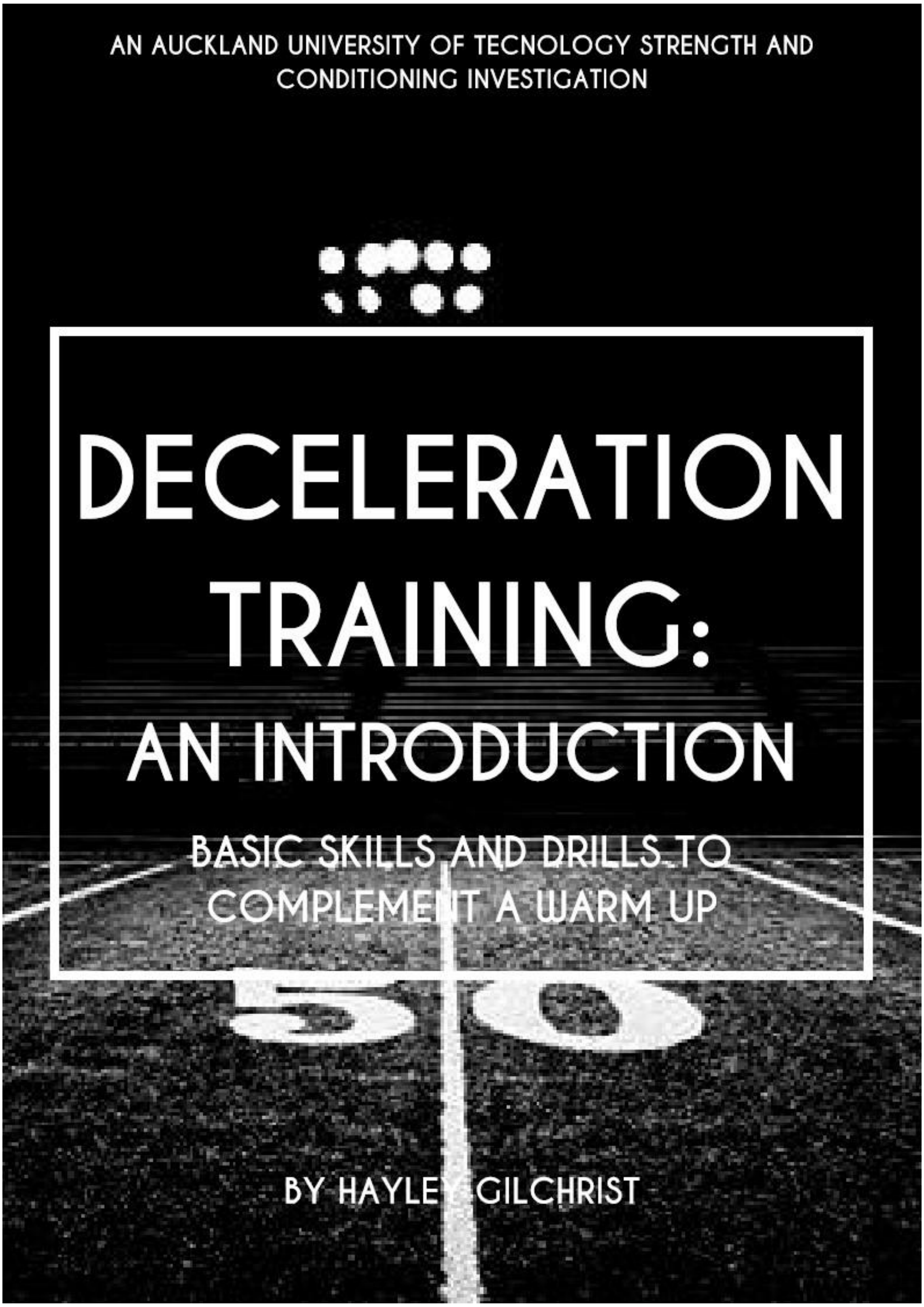
Training time (e.g. 1 hour) ______________________________

Training methods (e.g. weights, long running, skills) ______________________________

Any other information ______________________________

____

Appendix G: Deceleration training intervention handout



INTRODUCTION

Increasing an athlete's ability to decelerate has many advantages, however we seldom see this component of performance trained in isolation like we do for speed, strength or endurance qualities.

Potential performance benefits of improving deceleration ability include:

- More line breaks
- More players evaded
- More tackles made
- More players defended
- More time and space to make decisions
- More attention focusing on game situations

These performance improvements are due to a player being able to rapidly decelerate from a high sprint speed in a short space of time or distance. Therefore being more effective during the subsequent change of direction and increasing general competitiveness on field.

Potential injury prevention benefits may include:

- Increased stability
- Increased strength
- Increased force absorption

The likelihood of injury during a contact sport is always a risk. ACL is the most common non-contact injury in rugby codes and occurs during a sudden or unplanned change of direction. Usually this occurs during the deceleration phase of the movement. If deceleration ability can be improved, the deceleration phase of change of direction may be less likely to be a risky movement on the field if developed during training. This component of training can easily be incorporated as part of a comprehensive team warm up at the beginning of a team training session.

Please follow the deceleration skills warm up as per the instructions to follow, or view the instructional video to guide your sessions.

https://youtu.be/OxtjO3yAn44

DECELERATION SKILLS WARM UP

please use this as your training warm up 2x per week for the next 6 weeks

MOBILITY

Knee to Chest Walk – 10m

Hold for a few seconds before changing legs.

Heel to Butt Walk – 10m

Hold for a few seconds before changing legs.

Lunge Walk – 10m

Put weight on the front leg, pushing through the floor to stand up.

Squat Walk – 10m

Take 3 steps in between facing opposite directions each time. Aim for full range of motion, with chest up and fingertips at ears, not letting the elbows come forward.

Hamstring Sweeps – 10m

Sweep arms through reaching from the back foot through to the front foot, try to get full range of motion.

Leg Swings – 20m

Swing the leg through full range of motion, keeping the grounded leg strong and tall through the hips. Try not to bend the ground leg to get the swinging leg higher.

RUNNING TECHNIQUE DRILLS

Forward Skips - Low 2x10m

Stay relaxed and swing arms in a natural running style

Stay tall through the hips, get full range through the ankle

two feet will on the ground at once to perform a very low skip

Forward Skips - Medium 2x10m

Push harder into the ground to gain more distance and allow the knee to rise through a greater range of motion

Stay tall, trying to get height with each step

Absorb each step, keeping a relaxed rhythm with toes up and natural arm swing

Backward Skips - Low 2x10m

Push backward off the front leg, still staying low

Stay relaxed with a natural running arm

Stay tall through the hips and try to get full range of motion through the ankle

Plant the foot under the body or slightly behind to keep pushing backward

Backward Skips - Medium 2x10m

Push back off the front leg, with natural running arms and range of motion

Aim to get height and distance when pushing back during each step

Absorb each step and maintain the pushing back off the front leg motion

Try to stay relaxed with toes up and natural running arm swing

A-Skips 2x10m

- Move lower body through the full range of motion during this skipping drill
- When the foot strikes the ground during this drill, both feet will be planted at the same time
- Then pick the next leg up to carry on the rhythm *this drill is very rhythmic and will take practice
- Stay relaxed and allow arms to swing naturally in sync with the leg movements. Always keep toes up in preparation for striking the ground
- Keep the grounded leg strong pushing back into the ground as the swing leg moves to the top range. Stay tall during the whole drill

B-Skip 2x10m

- This drill has the same rhythm and instruction as the A-Skip
- Bring the knee up with toes up, staying tall with a strong ground leg
- Kick the lower limb out in a cycling motion, keeping tall with toes up
- Straighten leg with toes staying as upright as possible, keep arms swinging naturally
- Strike the ground under the body with a straight leg pushing into the ground in preparation for the next stride

High Knee Run 2x10m

- Move limbs through full range of motion for running, always keep a strong grounded leg with toes up. Always stay relaxed with swinging arms
- When switching legs there will be no feet touching the ground, switch legs as quickly as possible, still staying tall and upright
- Strike the ground with a strong leg under the body while the other leg is now in the top range preparing to switch legs once again

DECELERATION DRILLS

Drop and Stick

Double Leg 5x | Single Leg 3x ea side | Lunge 3x ea side

- Reach arms above and raise onto toes, be as tall as you can
- Drop into a strong position similar to a ¼ squat, where you feel as if you are balanced and stable, where no one could push you over from any direction
- Reach arms above and raise onto toes, be as tall as you can
- Drop into a single leg ¼ squat position, stick this landing and aim to have no up or down, or side to side movement. Stay as controlled and strong as possible in this position. You will see that the shoulders and ankles are staying close to the centre, splitting the load evenly in front of and behind the body
- Reach arms above and raise onto toes, be as tall as you can
- Drop into a lunge position, try to not have a soft landing, keep side to side movement at a minimum. A strong position is to have the knee under the hips to spread the load evenly in front of and behind the body. Have feet planted at least hip width apart or wider to maintain a stable base

Drop, Stick and Jump

Double Leg - 5x

- Reach arms above and raise onto toes, be as tall as you can
- Adopt the same ¼ squat positions as previously in the drop and stick
- This time the goal is to then leave the ground as quickly as possible after sticking the landing, trying to achieve as much height as possible on the jump, and being as tall as possible through the hips during the jump
- Land safely back down in the ¼ squat position and stick the landing as previously done in the drop and stick

Single Leg 3x ea

- each arms above and raise onto toes, be as tall as you can
- Adopt the same single leg ¼ squat positions as previously in the drop and stick
- Push hard into the ground off that single leg to initiate the jump and get tall through the hips
- Leave the ground as quickly as possible to jump as high as possible
- Land safely back down in the ¼ squat position with both feet planted and stick the landing as previously done in the drop and stick

Lunge 3x ea

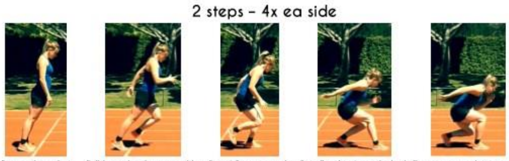
- Reach arms above and raise onto toes, be as tall as you can
- Adopt the same lunge position as previously done in the drop and stick lunge.
- Jump as quickly as possible after sticking the landing, use arms to help gain momentum. Try to jump as high as possible and get as tall as possible through the hips
- Land safely back down in the ¼ squat position with both feet planted and stick the landing as previously done in the drop and stick

Fall and Stop

3 steps – 4x ea side

- Begin with two feet together and arms at sides
- Fall forward as far as possible, aiming for no lower than 45 degrees, bring the chosen leg forward in front of the body to prepare for landing
- Step 1, Begin to apply breaking forces by starting to reposition the body to stop falling forward
- At certain points there will be 2 feet touching the ground to spread forces evenly through the body
- Step 2, plant the food in front of the body to apply breaking forces, sit back in the heels and get into a low position
- Step 3 Come to a complete stop with the final step and strong breaking leg in front

2 steps – 4x ea side



- Begin with two feet together and arms at sides
- Fall forward as far as possible, aiming for no lower than 45 degrees, bring the chosen leg forward in front of the body to prepare for landing
- Step 1 Begin to apply breaking forces by starting to reposition the body to stop falling forward, starting to plant the foot in front of the body
- Step 2, sit back into the heels with the foot planted will in front of the body in a low stable position
- Come to a complete stop, with the upper body no longer traveling forward past the toes

1 Step - 4x ea side

- Begin with two feet together and arms at sides
- Fall forward as far as possible, aiming for no lower than 45 degrees, bring the chosen leg forward in front of the body to prepare for landing
- Step 1 use a strong breaking step with foot planted in front of the body, come to a complete stop and stay in control by having the upper body not continuing past the toes once momentum has stopped

Bound and Stick

1 Step – 2x 20m

Push off the ground leg, leaning forward to gain momentum from a low athletic position

Bring rear/swing leg in front of the body

Plant the foot in front of the body to apply breaking force and slow momentum

Come to a complete stop in a similar position to the single leg ¾ squat, stop all momentum before pushing off again

2 Steps – 2x 20m

Push off using the ground leg from a low athletic position

Trying to not use the swing leg for momentum

Bring the swinging leg through in with a forward lean, toes up

Strike the ground under the body as per a natural running stride

Push off once again for the second step, bringing the swinging leg through

Begin to reposition the body from a forward lean, to start sitting back into the heels

Extend the leg, and plant the foot in front of the body to apply breaking forces and stop momentum

Sit back into the heels in the single leg ¾ squat position, stop all momentum before initiating the next step

3 Steps – 2x 20m

Push off using the ground leg from a low athletic position

Step 1, try to strike the ground in a natural running stride with the leg under or behind the body to push forward

Push off with a forward lean, keeping toes up and arms swinging naturally

Step 2 again, try to strike the ground in a natural running stride with the leg under or behind the body to push forward

Begin to reposition the body from a forward lean, to start sitting back into the heels

Step 3, plant foot in front of the body to apply breaking forces, sit back in the heels to slow momentum and help the body get into a low position to stabilise

Come to a complete stop as quickly as possible, and do not push off again without stopping momentum completely

Rapid Deceleration

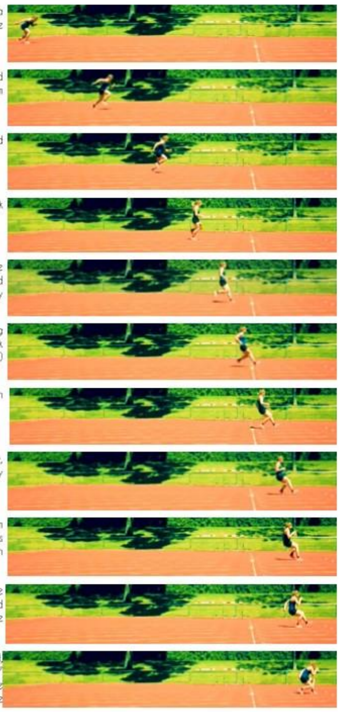
Perform the following to complete the skill session by putting the previous drills into practice at high speed.

This can be incorporated as part of a team skill training session, as part of a warm up prior to tactical or ball skills or as a short session on its own.

Set 1: 10m sprint/3m break zone x4

Set 2: 20m sprint/4m break zone x4

Try to complete each sprint at maximal sprint speed, not slowing down until the break zone begins. Alternate breaking legs between repetitions.



Start in a strong acceleration position, pushing out at a 45 degree angle at full sprinting pace

Drive knees forward and strike the ground slightly behind the body to create forward momentum

Naturally rise up and continue gathering speed

Continue sprinting all the way to the 10m mark

Once the 10m mark is reached, begin to reposition the body to move from a forward lean, to sit in the heels and lean backwards slightly

Plant the foot in front of the body to begin applying breaking forces once the athlete has entered the break zone (indicated at the white line in the image)

Lower the body to create a stable position

Keep weight in the heels with a lower centre of gravity, planting the foot in front of the body

Try to take as few steps as possible to stop within the 3m zone, control the upper body and limit the shoulders coming past the toes with a backward lean

fewer strong breaking steps over a short distance will be more effective than many soft steps over an extended distance

Come to a complete stop with one foot forward, alternate legs while performing these drills. Start with 7 steps, reduce it to 5, then 3 steps to stop within the break zone

Appendix H: Deceleration training intervention video link: https://youtu.be/0xtj03yAn44

Appendix I: Participant attendance record for men

Session Attendance Eastern Suburbs Men's Club Rugby Team

ID	22/01/18	24/01/18 week 1	29/01/18	31/01/18 week 2	5/02/18	7/02/18 week 3	12/02/18	14/02/18 week 4	19/02/18	21/02/18 week 5	26/02/18	28/02/18 week 6	Final Testing 5/03/18	Sessions attended out of 12	
M1	1	1	1	1	1	0	0	1	1	0	1	1	1	9	75%
M2	1	1	1	1	0	0	1	1	0	0	1	1	1	8	67%
M3	1	1	1	0	1	1	1	0	1	1	0	1	1	9	75%
M4	1	0	0	1	1	0	1	1	0	0	1	1	1	7	58%
M5	1	1	1	0	0	1	1	0	1	0	1	1	1	8	67%
M6	1	1	1	1	1	1	0	0	0	0	1	1	1	8	67%
M7	1	1	1	1	1	1	0	1	1	0	1	1	1	10	83%
														mean	70%
														std dev	8%