STRENGTH, SPEED-STRENGTH AND PERFORMANCE IN CHANGE OF DIRECTION TASKS IN RUGBY UNION ATHLETES

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Abstract

Previous research has shown that performance in change of direction (COD) tasks will be dictated by task-specific mechanical constraints, and individual-specific neuromuscular characteristics. Also, changes in performance in COD tasks will be specific to training mode and the individual. The overarching research question of this thesis was "how can performance in COD tasks be enhanced in rugby union athletes?"

The first aim was to identify neuromuscular qualities associated with performance in COD tasks. Second, to investigate categorical differences (forwards vs. backs) and relationships between strength, jump and COD measures. Lastly, the influence strength and jump training interventions have on category- and task-specific COD performance was investigated.

When performance was defined as time to complete the COD task, the main findings were: (1) the reliability of general and sport-specific COD assessments are unique to the group in question, (2) categorical differences (e.g. backs vs. forwards) in performance were observed, (3) mechanical determinants of performance were task-specific, (4) performance was associated with the expression of net force relative to time, (5) meaningful task-specific improvement in COD performance was concomitant with meaningful improvement in strength and jump measures, and (6) following training intervention individuals rated as 'slow' at baseline experienced a greater positive response than their 'fast' counterparts.

Several practical applications may be offered from the findings. First, practitioners are encouraged to select general and sport-specific COD assessments and establish the reliability of each assessment within the group to be trained. Second, categorical differences in COD performance suggest practitioners monitor performance within

defined sub-groups in accordance with manoeuvres association with those experienced in competition. Third, eccentrically-emphasised resistance training has applications for COD tasks that require large magnitudes of direction change – i.e. requiring full deceleration prior to acceleration in the new direction. Fourth, accentuated jump training appears to have application to performance in COD tasks that require smaller magnitudes of direction change. Finally, practitioners are encouraged to monitor within-individual changes in performance measures to specifically address the needs of the athlete, and increase the likelihood of individual-specific performance enhancement.

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TO GOD BE THE GLORY. To my Keeper, my Provider, my Way-maker, my Shield, my Sword, my Strength, my Sling and Stone, my Conqueror, my Fortress, my Refuge, my Comforter, my Healer, my Restorer, my Counselor, my Peace, my Banner, my Friend. THANK YOU! To the One who fed me when no one else could. To the One who reached me when no one else could. To the One who walked with me when no one else could. To the One who encouraged me when no one else could. To the One who lifted me when no one else could. To the One who taught me when no one else could. THANK YOU and BLESS YOU! All Glory, Honour and Praise belong to You Sir! *Hallelujah!*

"Blessed be the Lord, who has heard the sound of my pleading. The Lord is my strength and my shield in whom my heart trusted and found help. So my heart rejoices; with my song I praise my God."
Psalm 28:6

"Not to us, Lord, not to us but to Thy Name be the glory for Thy faithfulness and love." Psalm 115:1

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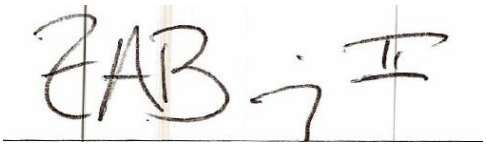
Attestation of Authorship

"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 (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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Co-authored Works

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

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Prof Mike R McGuigan	Assoc Prof Nic D Gill	Dr Paul Gamble
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Publications Arising from the Thesis

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Bourgeois FA, McGuigan MR, Gill ND, Gamble P. Physical characteristics and performance in change of direction tasks: a brief review and training considerations. *Journal of Australian Strength and Conditioning* 25(5): 104-117, 2017.

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Bourgeois FA, Gamble P, Gill ND, McGuigan MR. The relationship between multidirectional jumping and performance change of direction tasks.
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Ethics Approval

Ethical approval for the thesis research was granted by the Auckland University of Technology Ethics Committee (AUTEC) on 25 February 2016 for three years:

- AUTEC: 15/322 The role of strength and speed-strength in change of direction performance in rugby athletes.

Chapter 1 - Introduction

Rationale of the Thesis

Rugby is an invasion sport characterised by frequent bouts of high intensity sprints preceded by and followed by actions such as passing, kicking and tackling. Competitors seek to gain positional advantages by executing rapid changes of sprint direction to attack or defend against opposing players (Gabbett, 2009; Green, Blake, & Caulfield, 2011). Thus, performance in specific change of direction (COD) tasks have been identified as an important quality for rugby athletes (Swinton, Lloyd, Keogh, Agouris, & Stewart, 2014). Additionally, multiple athletic actions associated with rugby have been observed to be related to performance in COD tests (Gabbett, 2009; Green et al., 2011). For example, better tacklers have demonstrated faster performances in a modified 505 test (Gabbett, 2009). In a match context, COD capabilities are suggested to be an important component in successful match outcomes (Sheppard, Dawes, Jeffreys, Spiteri, & Nimphius, 2014; Wong, Chan, & Smith, 2012). Furthermore, rule changes set forth by the International Rugby Board have also encouraged teams to place a greater emphasis on acquiring and developing more agile athletes (Gabbett, 2009).

How muscle function contributes to performance in COD tasks has become an emerging area of research (Brughelli, Cronin, Levin, & Chaouachi, 2008; Sheppard et al., 2014; Spiteri et al., 2014). Research has shown athletic capabilities, such as COD, to be closely associated with strength (McCormick et al., 2014; Spiteri et al., 2015; Spiteri et al., 2014) and jump ability (Barnes et al., 2007; Lockie, Schultz, Callaghan, Jeffriess, & Luczo, 2014; Spiteri et al., 2014), as well as having specific responses to different modes of exercise (Arcos et al., 2014; Cronin, Brughelli, Gamble, Brown, & McKenzie, 2014). In addition, intrinsic properties of muscle have been demonstrated to be related to performance in jumping and sprinting tasks (Brughelli et al., 2008; Keitaro Kubo, Ikebukuro, Yata, Tomita, & Okada, 2011; Stafilidis & Arampatzis, 2007). These findings coupled with more recent investigations have begun to reveal the mechanical factors that may determine faster COD performances, and potentially hold implications for enhancing COD capabilities (Spiteri, Cochrane, Hart, Haff, & Nimphius, 2013; Spiteri et al., 2015; Suzuki, Ae, Takenaka, & Fujii, 2014). Furthermore, these findings may also have implications for enhancing performance in events that immediately precede and follow changing sprint direction (i.e. closing in on an opponent or escaping an opponent).

Within the literature, however, the impact muscle qualities have on performance in specific COD tasks is difficult to discriminate and is not entirely understood (Brughelli et al., 2008; Sheppard et al., 2014). Given the importance of COD ability in competition, substantial cross-sectional research advocates the stronger individual will perform better in COD tasks (Jones, Bampouras, & Marrin, 2009; Peterson, Alvar, & Rhea, 2006; Spiteri et al., 2013; Spiteri et al., 2015; Spiteri et al., 2014). This may be a consequence of the task employed in a controlled laboratory setting, and may be misleading when these findings are used to describe COD ability across a variety of sporting tasks. More research is needed concerning the specific interaction mechanical parameters of various COD tasks have with neuromotor capacity (i.e. strength) and capabilities (i.e. speed-strength).

In addition, there is a paucity of experimental research that explores training muscle characteristics significantly correlated with performance in specific COD tasks. Athletes, coaches and sport scientists consider performance in COD tasks important for athletic success resulting in its enhancement being heavily emphasised in strength and conditioning programmes (Brughelli et al., 2008; Young & Farrow, 2006). Therefore, understanding mode-specific training-induced responses is of importance.

Purpose of the Research

An aim of this thesis was to highlight the often overlooked task-specific nature of 'COD performance'. To define 'COD ability' this thesis used a modified version of the definition of skill proposed by Edwin R. Guthrie in 1952, which states "the ability to bring about some end result with maximum certainty and minimal outlay of energy, or of time and energy" (p. 136) (Guthrie, 1952). The definition of COD ability, as it pertains to cross-sectional and intervention performance measures of this thesis, is defined as the task-specific capability of achieving faster sprint times (end result) in 180-degree and 45-degree COD tasks with maximum certainty (repeatability) and minimum outlay of time. The criterion measure of COD capability in this thesis is time to complete a specific task. The specificity denoted by the definition and criterion measure of 'COD performance' used in this thesis is supported by the hypothesis of specificity proposed by Franklin M. Henry in 1958, which predicts performance will be particular to the task, and practicing or training any task other than the particular task will have minimal 'transfer' to performance (Henry, 1958). While the task-specific nature of performance cannot be denied (Bain & McGown, 2010; Sale, 1988), it is also important to note that enhancing neuromuscular capacities and capabilities via

systematic training can augment performance in tasks such as changing sprint direction (Brughelli et al., 2008; de Hoyo et al., 2015; Dobbs et al., 2017; Iacono et al., 2017), and thus is worthy of investigation.

The primary aim of this thesis was to investigate COD capabilities in the context of velocity change – that is, a change in the magnitude of direction and speed. The two tasks selected to assess COD capabilities were designed to describe performance in COD tasks that largely differ in both direction and speed change. Serial tasks (i.e. tasks that involve distinct movements in series) (Schmidt & Lee, 2013) that required one COD between two straight-line sprints were selected to minimise confounding factors such as extended sprint times (e.g. Illinois test) and multiple discrete actions about the COD (e.g. T-test).

To answer the overarching question "how can performance in COD tasks be enhanced in rugby union athletes?" this thesis sought to identify factors that underpin large and more modest changes in sprint direction at speed. Secondly, this thesis investigated the efficacy of different training modalities in relation to specific COD tasks. Six investigations were undertaken to specifically:

1. Investigate neuromotor characteristics associated with faster performances in COD tasks [Literature review];
2. Investigate the efficacy of various training modes on performance across an array of COD tasks [Literature review];
3. Determine the reliability and association between jumping and COD tasks [Study 1 and 2];
4. Evaluate the influence strength and speed-strength profiles have on performance in COD tasks in male football code athletes [Study 3];
5. Examine the influence of a 6-week eccentrically-emphasised strength training programme on performance in COD tasks [Study 4];
6. Examine the influence of a 4-week multidirectional accentuated jump training programme on performance in COD tasks [Study 5].

Significance of the Thesis

Answering the overarching question was governed by both theoretical and practical significance. Theoretical significance was defined as observations that support the thesis' theoretical framework. Practical significance was defined as information (e.g.

conclusions drawn from observations) and tools (e.g. COD tasks) that can be readily used in the physical preparation of rugby code athletes.

The ability to rapidly change sprint direction is considered essential for success in rugby codes (Brughelli et al., 2008; Sheppard et al., 2014). Consequently, assessment of COD capabilities is used in talent recruitment and selection, emphasised in athletic development, and highlighted as important to in-game performance. Presently COD capabilities and the factors suggested to facilitate performance enhancement appear to be often inaccurately generalised and oversimplified. Though it is accepted agility and COD are distinct athletic skills (Young, James, & Montgomery, 2002), coaches and sport scientists often overlook the task-dependent relationship specific muscle qualities (i.e. strength and speed-strength) have with a given COD manoeuvre. Failure to acknowledge different COD tasks require distinct physiological and mechanical demands would explain the conflicting findings within the literature. Not recognising the task-dependent nature of performance in COD tasks could also misdirect training focus and potentially attenuate performance enhancement subsequent to training.

It is difficult to completely measure this multi-faceted quality with one assessment. Research investigating relationships between mechanical factors and time-trial data within 180-degree and 45-degree COD tasks is warranted. The examination of these two tasks will provide preliminary information regarding respective parameters that distinguish COD tasks and factors that underpin faster performances. Specifically, the interaction between approach speed, COD step quantities, exit speed and time to complete the task requires more research. Understanding the relationship between momentum (massΔvelocity), impulse (ForceΔtime) and task performance will give coaches and scientists insight into elements that distinguish performance in COD tasks that require large and more modest velocity changes. Research describing the relationships physical attributes have with task-specific COD performance is currently limited. Specifically, the association unilateral strength, joint-specific torque and jump ability have with performance in COD tasks that require larger and more modest velocity changes requires further investigation. To date, COD research largely underestimates the complexity of this quality, and oversimplifies the influence physical characteristics have with COD capabilities. Further analysis of the factors that underpin faster performances with respect to COD tasks that require large and more modest direction changes would provide a more comprehensive understanding of this multi-factorial quality.

The investigation of training methods used to improve identified strength and jump qualities, and the subsequent influence respective enhancement has on performance in COD tasks that require large and more modest velocity changes will contribute to the current literature. This knowledge can facilitate the structuring and timing of strength and conditioning programmes aimed at enhancing task-specific capabilities. Subsequently the assessment and programming strategies used in this thesis are pertinent, not only to rugby codes, but to a multitude of field- and court-based sports, and may be applied to developmental, club-level, regional, professional and elite populations.

Structure of Thesis

This thesis is composed of four inter-linked sections (Figure 1.1). The first section contains a comprehensive literature review exploring physical characteristics associated with faster performances in COD tasks, and effective intervention methods for improving performance in COD tasks (Chapter 2). The second section consists of a series of cross-sectional studies. The first study of this section determined the usefulness of individualised multidirectional jumps (MDJ) and 180-degree and 45-degree COD tasks used in this thesis (Chapter 3). The second study examined stance-phase kinetics of the MDJ and 180-degree and 45-degree COD tasks, and the relationship stance-phase kinetics have with performance outcome in respective tasks (Chapter 4). The third study investigated strength and speed-strength characteristics associated with faster performances in 180-degree and 45-degree COD tasks (Chapter 5). The third section consists of two training intervention studies aimed at improving qualities identified as significant in Chapters 2, 4 and 5. The first training intervention examined the effects of a 6-week eccentrically-emphasised strength training on 180-degree and 45-degree COD performance in adolescent rugby union players (Chapter 6). The second training intervention examined the effects of a 4-week multidirectional accentuated jump training on 180-degree and 45-degree COD performance in adolescent rugby union players (Chapter 7). The final section provides a thesis summary, practical applications and direction for future research (Chapter 8).

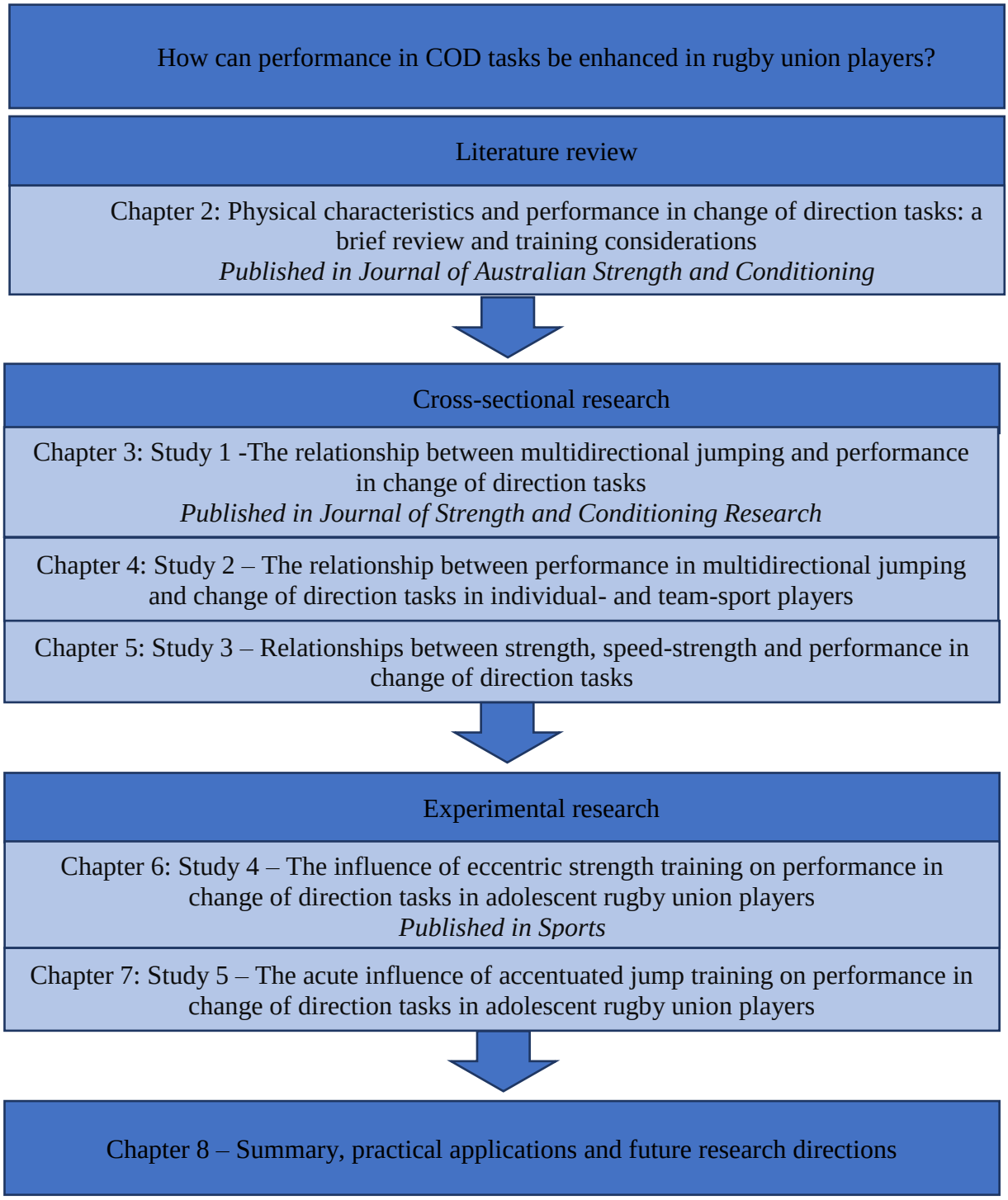

Figure 1.1. Thesis flowchart.

Chapter 2 – Physical Characteristics and Performance in Change of Direction Tasks: A Brief Review and Training Considerations

This chapter comprises the following publication in *Journal of Australian Strength and Conditioning*.

Reference:

Bourgeois FA, McGuigan MR, Gill ND, Gamble P. Physical characteristics and performance in change of direction tasks: a brief review and training considerations. *J Aust Strength Cond* 25(5): 104-117, 2017.

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Introduction

A challenge encountered in the physical preparation of several field- and court-based sports is enhancing the athletes' proficiency to move more efficiently and more rapidly during tasks that require changes in direction executed at speed. Frequent rapid direction changes (both anticipated and unanticipated) are a feature of many sports. Therefore, the capacity and capability of executing change of direction (COD) movements have been identified as critical for a variety of sports, including American football (Robbins, 2010), rugby codes (Condello et al., 2013), basketball (Spiteri et al., 2014), and soccer (Chaouachi et al., 2012). Change of direction ability refers to the task-specific capability of changing the direction of motion. While this ability depends largely on the task, a COD task generally necessitates a positive acceleration followed by a negative acceleration, a change in the direction of motion, followed by a positive acceleration in the new direction (Schot, Dart, & Schuh, 1995; Spiteri et al., 2013; Spiteri et al., 2015).

A broad range of COD tasks are encountered during match play, which involve varying degrees of direction change. In addition to the angle of direction change another key consideration when describing COD tasks is the amount of change in speed. Both of these factors (the degree of direction change and the speeds at which the task is completed) can be accounted for if the vector quantity of velocity is considered. As a vector quantity, velocity is expressed in terms of both magnitude (speed) and direction (Rodgers & Cavanagh, 1984; Winter et al., 2016). Therefore, if COD tasks are described in terms of changes in these two factors, understanding regarding physical preparation and performance outcome is gained due to highlighting the fundamental components of COD maneuvers – that is, mass, velocity (speed and direction), net force and time.

Newtonian Laws of Motion in relation to Change of Direction tasks

By defining COD tasks in terms of velocity change, practitioners can gain insight into the mechanisms that underpin performance outcome. This is primarily due to motion (i.e. performance) being described in terms of inertia (body mass), acceleration (strength and sprint ability) and force (strength). Consequently, consideration of these quantities has been proposed when investigating performance in COD tasks (Hori et al., 2008; Miller, White, Kinley, Congleton, & Clark, 2002; Sheppard et al., 2014; Spiteri et al., 2015; Vanrenterghem, Venables, Pataky, & Robinson, 2012). Most importantly, not

only have these variables been shown to be significantly associated with performance in COD tasks (Baker & Newton, 2008; Barnes et al., 2007; Chaouachi et al., 2009; Chaouachi et al., 2014; Chaouachi et al., 2012; Delaney et al., 2015; Jones et al., 2009; Lockie, Callaghan, et al., 2014; Lockie, Schultz, et al., 2014; Lockie, Schultz, Jeffriess, & Callaghan, 2012; Spiteri et al., 2015; Spiteri et al., 2014; Vanrenterghem et al., 2012; Young et al., 2002), favorable modifications of these components via training have been reported (Cormie, McGuigan, & Newton, 2011; Faigenbaum et al., 2007; Keiner, Sander, Wirth, & Schmidtbleicher, 2014; Miller, Herniman, Ricard, Cheatham, & Michael, 2006; Sale, 1988; Salonikidis & Zafeiridis, 2008; Thomas, Comfort, Chiang, & Jones, 2015; Thomas, French, & Hayes, 2009; Walklate, O'Brien, Paton, & Young, 2009). Therefore, describing performance in COD tasks with reference to Newton's Laws of Motion is appropriate.

Newton's first law relates to inertia and force; a body at a constant velocity (which can be zero) will remain at that velocity unless acted upon by a force. Inertia, or the amount of resistance to a change in direction and speed, will be largely relative to the mass a body possesses. Concerning COD maneuvers, this means an athlete will continue to travel in their current state until he or she applies a force to the ground (i.e. plant-step; discussed later) to change their speed and direction of motion. The magnitude of net force needed to change speed and direction will be predicated on the athlete's body mass, initial speed and the angle of direction change required. The importance of force generating capacity relative to body mass is highlighted as both the mass of the athlete and the amount of change in speed and direction are critical variables that determine force requirements (Sheppard et al., 2014; Suchomel, Nimphius, & Stone, 2016).

This concept is underscored by Newton's second law which defines the relationship between mass, acceleration (change in velocity) and net force. Acceleration will occur in the direction of the net force, while the magnitude of acceleration will be proportionate to the magnitude of force and inversely proportionate to mass. Relative to COD maneuvers, this relationship is fundamental in describing the strength requirements to change velocity (i.e. acceleration) for a given task. This relationship between mass, acceleration and force once more highlights the influence relative strength will have on performance outcome.

Lastly, Newton's third law states for every force there is an equal and opposite force exerted. Relative to COD maneuvers, this net reaction force is the mechanism for generating the propulsion that facilitates the COD (DeWeese & Nimphius, 2016; Schot

et al., 1995; Spiteri et al., 2015). When an athlete imparts a net force to the ground during the plant-step, the ground returns a propulsive net force of equal magnitude to the athlete in the opposite direction. Contextually, this means to effect the desired change in speed and direction, the individual must impart a net force of the required magnitude in the appropriate direction and orientation during the COD maneuver (DeWeese & Nimphius, 2016; Schot et al., 1995; Spiteri et al., 2015).

As such, the ability to perform COD movements is governed by task-specific physiological and mechanical parameters that distinguish it from other athletic capabilities (Hewit, Cronin, & Hume, 2013; Salaj & Markovic, 2011; Young & Farrow, 2013; Zamparo, Zadro, Lazzer, Beato, & Sepulcri, 2014). Accordingly, several authors have identified COD ability and agility to be discrete qualities (Brughelli et al., 2008; Young & Henry, 2015; Young, McDowell, & Scarlett, 2001). Change of direction abilities must also be distinguished from agility in sports. Agility has been defined as a whole-body movement that involves a rapid change in speed and direction in response to a stimulus (Sheppard & Young, 2006). Consequently, what differentiates COD from agility is the absence of cognitive components, such as perception-action coupling and decision making, associated with the task (Sheppard et al., 2014; Sheppard & Young, 2006). Given these capabilities are distinct, it follows that the development of COD versus agility will require somewhat different methods (Hori et al., 2008; Salaj & Markovic, 2011; Sheppard & Young, 2006; Spiteri et al., 2014; Young & Farrow, 2013; Young & Henry, 2015; Young et al., 2001).

Nonetheless there remains a need to develop the ability to perform COD tasks. In addition to serving as a foundation quality with respect to athletic development, there are a number of instances during competition in several sports that involve an element of pure pre-planned COD. Examples include gaining positional advantage in attacking and defending the opposition in evasion sports; maneuvering about fixed bases in batting sports; and repositioning movements (e.g. “returning to the ‘T’”) in racquet sports. Though there are data demonstrating limited association with subsequent success (Kuzmits & Adams, 2008; Robbins, 2010), pre-planned COD assessments are widely featured in test batteries employed for talent identification and selection (Pyne, Gardner, Sheehan, & Hopkins, 2006; Sierer, Battaglini, Mihalik, Shields, & Tomasini, 2008; Stewart, Turner, & Miller, 2014), with performance in these assessments being shown to be related to draft selection and becoming contracted in professional sports (Burgess, Naughton, & Hopkins, 2012; Kuzmits & Adams, 2008; McGee & Burkett, 2003; Sierer

et al., 2008). Moreover, performance in these COD tasks has been shown to be associated with subsequent success at respective positions (Burgess et al., 2012; Sierer et al., 2008).

Developing the capacity to execute COD tasks is therefore a goal in strength and conditioning programmes across a wide array of field- and court-based sports (Cowley, Ford, Myer, Kernozek, & Hewett, 2006). Performance in COD tasks has been shown to be affected by a variety of factors, including age (Condello et al., 2013; Hoffman, Tenenbaum, Maresh, & Kraemer, 1996; Holmberg, 2009; Jakovljevic, Karalejic, Pajic, Macura, & Erculj, 2012), playing level of athletes (Brughelli et al., 2008; Condello et al., 2013), type of athletes (Cowley et al., 2006; Vescovi & McGuigan, 2008), ranking on the depth chart (Brughelli et al., 2008) – that is, starters versus reserves – and playing time (Hoffman et al., 1996). However, the relationship between a particular COD assessment and the ability to execute COD tasks encountered in the sport is difficult to determine and is dependent upon the particular assessment(s) selected.

Furthermore, the effects of developing certain strength and speed-strength qualities through different training interventions, and the specific impact each will have on task-specific COD performance is yet to be fully elucidated. The purpose of this article is to provide a brief review of (1) COD assessment, (2) physical attributes thought to be important in COD capabilities, and (3) training modalities believed to be key in enhancing the ability to change direction. Also, evidence-based recommendations are provided to aid the practitioner with practical application.

Methods

The literature reviewed was attained via web-based search using PubMED, SPORTDiscus, ScienceDirect, and Google Scholar. Keywords used to identify relevant articles were *change of direction performance*, *change of direction ability*, *agility*, *pre-planned tasks*, *athletic performance*, and *multidirectional sprinting*. Initially 197 articles were collated. Specific inclusion criteria included 1) peer-reviewed articles, 2) change of direction tasks, 3) pre-planned tasks, 4) detailed explanation of procedures and methods where appropriate, and 5) research studies with human participants. These criteria excluded a total of 121 articles. Exclusion criteria were 1) duplicate articles, 2) previous research whose data were similar to current findings, 3) poorly explained procedures or underdeveloped methodology, and 4) unplanned tasks.

Discussion

Change of direction assessment and potential performance influences

The assessment of COD ability can be done via pre-planned tasks. There are a multitude of tests used to assess COD ability. Established assessments are the 505 (one 180-degree direction change), pro agility test (two 180-degree direction changes), L-drill (two 90-degree and one 180-degree direction changes), T-test (two 90-degree and two 180-degree direction changes), slalom run, and Illinois test (Brughelli et al., 2008; Sheppard et al., 2014; Sheppard & Young, 2006; Stewart et al., 2014). There are also assessments that have been developed for sport-specific evaluation (Baker & Newton, 2008; Walklate et al., 2009).

Regarding the analysis of performance, trends, associations, and efficacy of interventions are quantified statistically (Turner et al., 2015). Traditionally, time to complete the COD test has served as the performance measure, with the change in mean used to quantify trends (i.e. enhancement or decrement). When considering the statistical approach for evaluating performance it is recommended to calculate the mean of all trials executed. Recently, average performance was shown to be a more sensitive measure than peak performance when monitoring neuromuscular status via vertical countermovement jump (CMJ) performance (effect size (ES) = -0.56 vs. -0.04) (Claudino et al., 2017).

The number of trials required to attain the most accurate and precise data can be attained by examining session reliability (i.e. between- and within-session) and individual reliability (i.e. between- and within-individual) over a duration equal to that of the intervention (Hopkins, 2000). Nonetheless, allotting 2 to 5 trials per task with a minimum of 2 familiarisation attempts is recommended (Stewart et al., 2014). The average of 2 to 5 maximal effort trials following 2 maximal effort familiarisation attempts provides a more accurate and precise approach to monitoring team (i.e. group) and athlete performance. The additional information also allows the calculation of validity and reliability statistics such as intraclass correlation coefficient, coefficient of variation and typical error of measurement (Hopkins, 2000). In addition, Pearson's correlation coefficient (r) and coefficient of determination (r^2) can be used to quantify the relationship strength and jump measures have with performance in COD tasks (Brughelli et al., 2008; Turner et al., 2015).

Categorising change of direction tasks

Two key characteristics can be used to distinguish COD assessments and may aid in practical application (Brughelli et al., 2008; Robbins, 2011; Zamparo et al., 2014). The first is time to complete the test, which is measured in seconds (s). Assessments can be categorized as 0-5 s (e.g. pro agility test), 5-9 s (e.g. T-test), and ≥10 s (e.g. Illinois test) (Brughelli et al., 2008). The second distinction is the number of direction changes the test requires. This has been described as 1-3 direction changes (e.g. L-drill), 4-6 direction changes (e.g. T-test), and ≥7 direction changes (e.g. Illinois test) (Brughelli et al., 2008).

It is important to note that the duration and intensity of a given COD task will dictate the relative contribution of anaerobic (ATP-PCr and glycolytic) and aerobic energy systems (Brughelli et al., 2008; Robbins, 2011; Zamparo et al., 2014). Recently, evaluating performance in COD tasks over larger distances has been questioned (Sayers, 2015). This is a critical factor to consider with respect to the physiological capacities involved. Anaerobic metabolism is generally accepted as the primary energy system used during COD assessment (Brughelli et al., 2008), however, it should be noted that energy metabolism during the assessment of COD performance will be dictated by the volume, intensity and duration of the testing protocol. Performance outcome in COD tasks with relatively longer durations, and longer testing batteries will be influenced by bioenergetics of the task(s) in relation to the capacities of the individual (Brughelli et al., 2008; Zamparo et al., 2014). The capacity to perform repeated bouts is also relevant to what occurs during competition; however, this is beyond the scope of this review.

The degree of direction change and the number of direction changes will dictate the kinematic and kinetic determinants of a COD maneuver (Lockie, Schultz, et al., 2014; Schot et al., 1995; Spiteri et al., 2015; Young et al., 2001). Also, the performance outcome of a single COD task must be kept in context, as assuming the results of one assessment effectively profiles overall COD ability is misleading (Holmberg, 2009). It can be argued that describing COD performance as a generic quality is a misrepresentation of a multi-faceted ability that is context-specific (Holmberg, 2009; Jeffreys, 2006; Salaj & Markovic, 2011; Young et al., 2001), and dependent upon the capabilities of the athlete. Caution should be used when findings reporting performance in one COD task are used to describe global COD performance which traverses a variety of tasks and sports. Arguably any COD assessment is only relevant to a particular COD task if they are closely similar and emphasise similar capacities and

capabilities (Holmberg, 2009; Sheppard et al., 2014; Sheppard & Young, 2006; Young et al., 2001; Zamparo et al., 2014). For instance, assessments that call for slight deviations from the approach direction are mainly representative of COD tasks that are more reliant on speed qualities (Schot et al., 1995; Sheppard et al., 2014; Young et al., 2002; Young et al., 2001). In this case, similar to other athletic tasks, performance is predicated more on the rate at which force is developed than the expression of maximal strength (Haff & Nimphius, 2012; Morin, Edouard, & Samozino, 2011; Suchomel et al., 2016). The emphasis of capability over capacity is driven by the short duration of time to express strength during the maneuver (Kugler & Janshen, 2010; Morin et al., 2011; Suchomel et al., 2016). In addition, the orientation of the resultant force observed during a multitude of COD tasks are often different from what occurs during generic bilateral strength assessment and exercise (e.g. barbell squat). Thus practitioners should be aware of the influence the selected COD assessment(s) may have on training focus. An illustrative example is the 505 test. This involves a 10 m run up at full pace prior to executing a 180-degree COD. Clearly this task represents an extreme COD maneuver that places a large emphasis on overcoming inertia to come to a complete halt prior to accelerating in the opposite direction. Hence, this task has an innate requirement for higher levels of force generation, and may compel the practitioner to place an inappropriate amount of focus on developing force capacity. It has also been recognised that COD assessments include movements and maneuvers specific to the sport in question (Holmberg, 2009; Jeffreys, 2006; Stewart et al., 2014; Young & Farrow, 2013; Young et al., 2001) (discussed later).

Additionally, it is proposed a continuum may exist when determining which mechanical factors are predominant in underpinning faster COD performances (Figure 2.1). The continuum may also aid in the mechanical description and explanation of various COD maneuvers. Figure 2.1 illustrates the kinetic factors that dictate performance in the penultimate step, the COD step and the post-COD step. Key components to consider are approach velocity (i.e. direction and speed), the angle of direction change, and post-COD task. As described earlier, high-velocity entry tasks that encompass COD angles in the range of 0-degree to 90-degree are more velocity-oriented (i.e. force capability), with the importance of force capacity increasing with the magnitude of COD angle. These tasks involve a more rapid COD-step with force exerted over a relatively short period of time. Conversely, high-velocity entry COD tasks that encompass angles of direction change in the range of 90-degree to 180-degree are more force-oriented (i.e. force capacity), with the importance of force capabilities increasing as the magnitude of

COD angle decreases. These tasks involve a rapid COD-step with force exerted over a relatively long period of time.

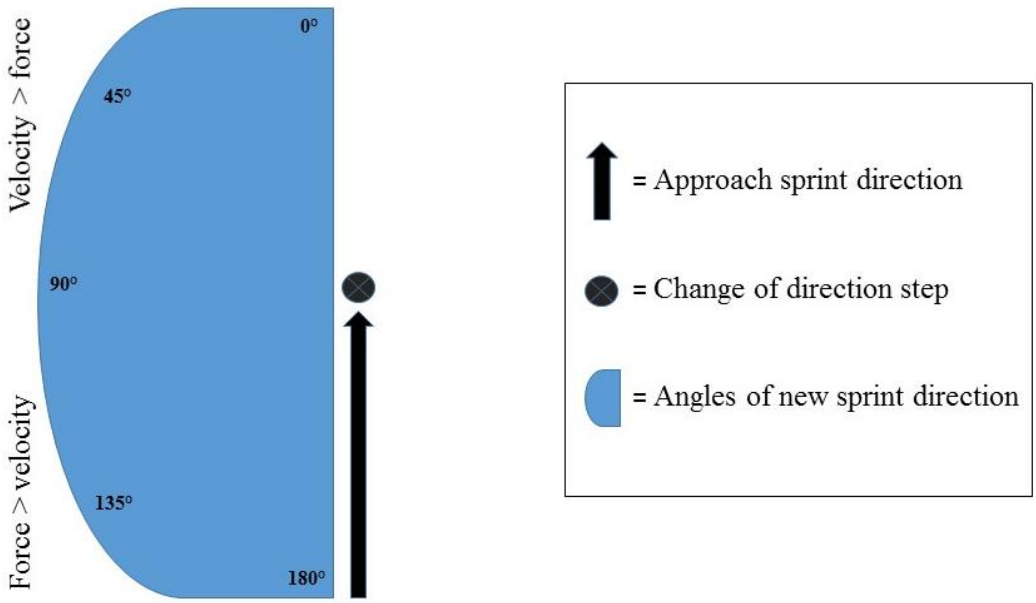

Figure 2.1. Continuum of mechanical determinants of changing sprint direction.

In addition to the accurate description and explanation of tasks within the sport, this information can be used to guide assessment selection and the foci of training sessions by specifically replicating the types of muscle actions and the velocities these muscle actions occur during competition. The details of this information can be attained via video analysis of the sport and respective positions (discussed later). Nonetheless, it is prudent for the practitioner to use general (e.g. the 505) and sport-specific tasks when assessing and training COD capabilities (Chaouachi et al., 2012; Holmberg, 2009; Jeffreys, 2006; Salaj & Markovic, 2011).

Age and performance outcome

There are several reports of performance in COD tasks fluctuating with chronological, biological and training age (Condello et al., 2013; Hirose & Nakahori, 2015; Holmberg, 2009; Jakovljevic et al., 2012; Keiner et al., 2014; Vescovi & McGuigan, 2008; Yanci, Los Arcos, Reina, Gil, & Grande, 2014). The influence of age on time to complete COD tasks and its potential to discriminate abilities can be observed in individuals as young

as 6 years of age (Yanci et al., 2014), and has been shown to extend into the under-19 age group (Condello et al., 2013; Keiner et al., 2014).

In young male team-sport athletes the quality of executing COD tasks has been observed to progress from more rounded turns to sharper sidesteps as age increases (Condello et al., 2013). This would suggest a need to shift training focus as athletes advance in age. The recommended progression to facilitate the influence of age on performance in COD tasks is to begin with basic pre-planned maneuvers with minimal direction changes to enhance gross movement skills, and advance to more complex sports-related movement skills training as biological and training age increases (see Table 2.3) (Condello et al., 2013; Holmberg, 2009; Jakovljevic et al., 2012).

Body mass and performance outcome

The body mass of the athlete is an important factor that determines inertia and in turn the magnitude of force required to change velocity. Similarly, the body mass of the athlete and their approach velocity will collectively determine momentum; and as Newton's 2nd law describes, the required change in momentum during the time interval of the COD maneuver determines forces involved. This phenomenon has been described as the momentum-impulse relationship (Rodgers & Cavanagh, 1984; Schot et al., 1995; Vanrenterghem et al., 2012; Winter et al., 2016). Specifically, the change in the product of mass and velocity ($m\Delta v$) is directly proportionate to the change in the product of force and time ($F\Delta t$).

Although relatively heavier individuals tend to generate greater levels of force (i.e. absolute strength), individuals with lower body mass have been shown to execute COD tasks faster than their heavier counterparts (Brughelli et al., 2008; Robbins, 2011). Therefore, it is more appropriate to consider COD performances with respect to body mass when relationships between performance outcome and other physical qualities (e.g. maximal strength) are examined (Peterson et al., 2006; Sheppard et al., 2014; Suchomel et al., 2016).

Strength and change of direction performance

Strength is considered foundational to overall athletic performance. This is primarily due to the importance of force-generating capacity with respect to overcoming inertia and effecting a change in momentum in order to change velocity. As such, strength is recognised as a critical factor for the expression of mechanical power (Cormie et al.,

2011; Haff & Nimphius, 2012; Stone, Moir, Glaister, & Sanders, 2002; Suchomel et al., 2016). There are some studies that report no association (Isoinertial and isometric back squat and 20-yard shuttle, r = -0.21 and 0.08, respectively; relative 3RM back squat and 90-degree COD test, r = -0.204; 1RM back squat and T-test, r = -0.169) (Chaouachi et al., 2012; Markovic, 2007; Peterson et al., 2006), or trivial (Right and left lateral shuffle test and 3RM back squat, r = 0.067 and 0.097, respectively) relationships between strength measures and performance in particular COD tests (McCormick et al., 2014; Young & Henry, 2015). However, many studies report significant correlations between maximal bilateral dynamic strength (1RM front squat and 180-degree COD test, r = -0.51; leg press and 180-degree COD test, r = -0.371; relative 3RM back squat and 180-degree COD test, r = -0.73 to -0.85; Relative 1RM back squat and T-test, r = -0.805; 1RM back squat and T-test and 180-degree COD test, r = -0.800 and r = -0.804, respectively) and performance in COD tasks (Hori et al., 2008; Jones et al., 2009; Nimphius, Mcguigan, & Newton, 2010; Peterson et al., 2006; Spiteri et al., 2014).

Though some data suggests absolute strength to possess a stronger statistical relationship with performance in COD tasks (absolute 1RM front squat vs. relative 1RM front squat, r = -0.51 vs. -0.37, respectively) (Hori et al., 2008), strength expressed relative to body mass appears to show a statistically superior association to that of absolute strength (Leg press vs. relative leg press, r = -0.371 vs. -0.446, respectively; 1RM back squat vs. relative 1RM back squat, r = -0.408 vs. -0.633 and -0.169 vs. -0.333, respectively) (Jones et al., 2009; Peterson et al., 2006; Sheppard et al., 2014). This can be readily explained given that COD tasks are determined to a large degree by the ability to overcome inertia (Sheppard et al., 2014). Recently, Spiteri and colleagues (2015) demonstrated individuals with greater overall strength scores on maximal dynamic barbell back squat were faster in completing COD tasks with both 180-degree and 90-degree direction changes.

Performance in COD tasks has also been shown to be largely associated with maximal bilateral eccentric strength (Relative 1RM strength and T-test and 180-degree COD test, r = 0.878 and -0.892, respectively) (Jones et al., 2009; Spiteri et al., 2014) and concentric strength (Relative 1RM strength and T-test and 180-degree COD test, r = -0.791 and -0.791, respectively) (Jones et al., 2009; Spiteri et al., 2014). Isometric bilateral strength has also been shown to be significantly correlated with performance in standard and modified versions of the 505 and T-test (r = -0.792 and -0.854, r = -0.57, respectively). (Spiteri et al., 2015; Spiteri et al., 2014; Thomas et al., 2015). Regarding

speed-strength exercises, such as the power clean, there is a lack of research investigating their relationship with COD capabilities. Nonetheless, Hori and colleagues (2008) found a moderate correlation (r = -0.41) between performance in 1-RM hang power clean and total time to complete a modified 505 test.

Considering many COD maneuvers appear to be predominantly executed from a unilateral base of support, there is a paucity of data describing the relationship between unilateral strength measures and performance in COD tasks. Current literature supports a relationship exists based upon data reported for isokinetic (Relative isokinetic eccentric knee extension and flexion and 180-degree COD test, r = -0.506 and -0.592, respectively; Relative isokinetic concentric knee extension and flexion and 180-degree COD test, r = -0.568 and -0.560, respectively; Concentric knee extension and eccentric knee flexion, r = -0.568 and r = -0.638, respectively; Concentric knee extension, r = -0.537) (Jones et al., 2009; Lockie et al., 2012; Negrete & Brophy, 2000) and isometric (Relative strength, faster vs. slower, 20.78 ± 2.13 $N \cdot kg^{-1}$ vs. 11.96 ± 3.50 $N \cdot kg^{-1}$, ES = 3.04) (Spiteri et al., 2013) unilateral strength measures.

It appears appropriate to incorporate high- and low-load bilateral and unilateral strength exercise (e.g. barbell back squat and box step-up) to facilitate neuromuscular adaptations considered favorable to performance in COD tasks. The emphasis of strength development should likely transition from predominantly bilateral exercise to unilateral exercise as preliminary data and anecdotal observation suggest single-leg strength is important for many COD maneuvers, particularly when considering braking and weight-acceptance (eccentric) and propulsive (concentric) portions of the COD activity (Hewit, Cronin, Button, & Hume, 2011; Spiteri et al., 2013; Spiteri et al., 2015).

Trunk strength and stability appear to be important in athletic performance (Hibbs, Thompson, French, Wrigley, & Spears, 2008; Kibler, Press, & Sciascia, 2006). However, there is a paucity of research investigating trunk strength as it relates to performance in COD tasks. Nesser and colleagues (2008) and Okada and colleagues (2011) each found inconsistent (i.e. non-significant to largely significant) association between measures of trunk stability and performance in the pro-agility test and T-test, respectively (r = -0.188 to -0.448 and r = -0.366 to -0.551, respectively). While these findings may suggest an association between trunk strength and performance in COD tasks exists, the findings must be interpreted with caution. It should be noted the measures of trunk stability employed involved muscular endurance tests; that is, tests that require an individual to maintain a certain posture until volitional failure. These

isometric muscle actions are sustained over relatively longer periods of time when compared to those potentially experienced during a rapid COD maneuver.

From a practical standpoint, strength in trunk segment musculature would be advantageous given their role in mobilising the trunk during locomotion, and in augmenting force transmission by providing a rigid connection between upper and lower extremities (Hibbs et al., 2008; Kibler et al., 2006). As such, it is appropriate to incorporate a training regimen that employs basic floor exercises with an emphasis on maintaining a neutral posture and isometric torsional stability in the sagittal, transverse and frontal planes (e.g. plank holds). Emphasis then shifts to more demanding exercises that include trunk rotation with a neutral spine (e.g. woodchoppers), as these involve both dynamic torsion development and stability. Future research should consider investigating assessments of trunk strength as opposed to endurance. This will necessarily involve a shorter, more rapid muscle action similar to that of the mid-thigh pull.

Jump ability and change of direction performance

Jump performance has been shown to be associated with several athletic movements, including COD tasks (Lockie, Callaghan, et al., 2014; Lockie, Schultz, et al., 2014). The use of jumping tasks as assessments and training tools is popular among coaches and sports scientist due to their validity, reliability and practicality. Currently, there are data supporting an association between multidirectional bilateral CMJ ability and performance in COD tasks (r = -0.358 to -0.788) (Barnes et al., 2007; Castillo-Rodríguez, Fernández-García, Chinchilla-Minguet, & Carnero, 2012; Lockie, Schultz, et al., 2014; Peterson et al., 2006; Vescovi & McGuigan, 2008; Yanci, Mendiguchia, & Brughelli, 2014). There are similar reports concerning multidirectional unilateral CMJ ability (r = -0.379 to -0.721) (Lockie, Callaghan, et al., 2014; McCormick et al., 2014; Meylan et al., 2009; Negrete & Brophy, 2000; Yanci et al., 2014). Recently, loaded (40 kg) vertical jump performance was found to be associated with the time to complete a single 180-degree COD task (r = -0.47 and -0.48) (Delaney et al., 2015). It should be noted, however, jump height and distance appear to have stronger relationships with COD tasks than other jump characteristics, such as jump power (r = -0.713 vs. -0.210, respectively) (Peterson et al., 2006; Sheppard et al., 2014).

When drop jump (DJ) performance is considered the data appear more equivocal (r = -0.291 to -0.536) (Barnes et al., 2007; Castillo-Rodríguez et al., 2012; Jones et al., 2009;

Lockie, Schultz, et al., 2014). This may be a consequence of the drop height employed (Bobbert, Huijing, & van Ingen Schenau, 1987b), variation of DJ technique (Bobbert, Huijing, & van Ingen Schenau, 1987a), and capabilities of the athlete with respect to optimal drop height (Ruan & Li, 2008). The reference COD task employed will also be a critical factor that will affect the relationship observed (Castillo-Rodríguez et al., 2012; Delaney et al., 2015; Lockie, Schultz, et al., 2014).

For instance, the rapid accentuated stretch-shortening cycle that occurs during a DJ appears to generate an impulse similar to that produced in COD tasks that call for smaller changes in the magnitude of velocity (Cormie et al., 2011; Suchomel et al., 2016), thus a smaller COD (e.g. ≤90-degree direction change). Lockie and co-researchers (Lockie, Schultz, et al., 2014) demonstrated this when two COD tests were compared. Each COD assessment consisted of two-90-degree direction changes. The distinguishing factor between the two tests was one test consisted of two-45-degree direction changes and the other consisted of two-180-degree direction changes. No correlation was found between DJ height ($r = -0.390$), contact time ($r = 0.445$) and flight time ($r = -0.380$) from a 40 cm box height and performance in the test with two-180-degree direction changes. Conversely, large association was found between DJ height ($r = -0.519$), contact time ($r = 0.611$) and flight time ($r = -0.526$) and performance in the test composed of two-45-degree direction changes.

Similar to strength training, it is suitable to emphasise bilateral jump training which progresses from unloaded to loaded and accentuated modes (e.g. body-weight vertical CMJ, 20 kg loaded vertical CMJ and 30 cm DJ, respectively). The next phase of training should include a similar progression beginning with unloaded unilateral jump training to more demanding loaded and accentuated unilateral jump training. More research considering multidirectional accentuated jump tasks and their relationship with COD tasks across the force-velocity spectrum (i.e. smaller velocity changes to larger velocity changes) is needed.

Straight-line speed and change of direction performance

Straight-line speed is considered to be an important athletic quality for field and court athletes (Hewit et al., 2013; Young & Farrow, 2013). Consequently, strength and conditioning programmes in these sports typically emphasise straight-line acceleration and speed development. Some authors speculate straight-line sprint speed to be an integral component of most COD tasks by assisting in the achievement of faster times

on related measures (Condello et al., 2013; Gabbett, Kelly, & Sheppard, 2008; Hewit et al., 2013; Jones et al., 2009; Peterson et al., 2006).

Conversely, some authors consider straight-line sprint ability and COD ability to be discrete qualities (Jakovljevic et al., 2012; Vescovi & McGuigan, 2008; Young et al., 2001). Indeed, the kinematic and kinetic requirements of different COD tasks are somewhat distinct from what occurs during the respective phases of straight-line sprinting. For instance, the mechanics of maximum velocity during straight-line sprinting are different from those during COD activities. That said, mechanics of the acceleration phase of straight-line sprinting can be viewed as broadly similar to the acceleration portions of COD activities. As such, enhancing straight-line sprint acceleration over relatively shorter distances (i.e. ≤10 m) can be seen as beneficial for initial and exit velocity for COD maneuvers (Vanrenterghem et al., 2012).

The degree of relationship between straight-line speed measures and COD assessments is shown to vary with the magnitude of angle change and the number of direction changes during the task (Young et al., 2002). For more obtuse COD angles executed at faster speeds, straight-line sprint abilities are likely to be more relevant. It can similarly be argued that straight-line sprint performance is inherently advantageous in COD tasks that feature relatively longer sprint bouts, such as the Illinois test (Sayers, 2015; Sheppard et al., 2014; Young et al., 2002). Considering the influence of entry velocity and the lengths of straight-line sprint paths during the assessment and training, practitioners are advised to strongly consider the length of each straight-line sprint segment about each COD-step and the total distance the COD task requires.

Technique training for change of direction performance

Unlike straight-line sprinting, training the technique of COD maneuvers is unclear. Seemingly, COD technique training should encompass a multitude of specific tasks primarily due to the kinetics and muscle activity differing significantly between sport (Cormie et al., 2011) and task (Chaouachi et al., 2014; Lockie, Schultz, et al., 2014; Rand & Ohtsuki, 2000; Schot et al., 1995; Spiteri et al., 2014; Suzuki et al., 2014). Furthermore, COD technique (Dempsey, Lloyd, Elliott, Steele, & Munro, 2009) and performance outcome (Bloomfield, Polman, O'Donoghue, & McNaughton, 2007; Chaouachi et al., 2014; Walklate et al., 2009; Young et al., 2001) have been shown to be modified following training, even in the absence of specialised equipment (Bloomfield et al., 2007; Gamble, 2011). Walklake and colleagues (2009) demonstrated

4 weeks of COD training improved performance in a sport-specific COD assessment (-3.6% ± 2.6%). Recently, Chaouachi and colleagues (2014) reported significant increases in performance in the Zigzag test and a 15 m COD task with and without a soccer ball following 6 weeks of COD training (-5.13% and -11.9%, respectively).

Considering the trainability of performance in COD tasks, it is appropriate to incorporate training for sport-specific COD tasks. However, due to the task-specific nature of COD performance testing and training should include tasks that put athletes in an environment that replicates in-competition situations. This could include an attacker and defender, and COD tasks with and without a ball or sport implement.

Practical Applications

With respect to athletic performance in field- and court-based sports, COD capabilities remain foundational. As such assessment of COD ability remains appropriate, and provides the practitioner with valuable information. General (i.e. established) and sport-specific assessments are recommended as each will present information on global and specific capabilities. Table 2.1 offers some examples of general and specific tests with respect to sport and position. Key factors to consider when selecting a COD assessment are distance and duration, the number of COD steps and their respective angles, and the orientation of the test (i.e. right plant leg or left plant leg). Similar to the influence of distance and duration of a single test, practitioners should be mindful of the influence the total number of COD tests will have on performance outcome. Therefore, the COD test battery – that is, the type of tests selected and the total number of tests selected – should be driven by the demands of the sport. Nonetheless, general and sport-specific assessments are warranted. When considering the approach to analysing the results, the average of 2 to 5 repetitions should be used to ensure reliability of the data.

Conceptualising performance in COD tasks in the context of Newtonian laws of motion demonstrates that force generating capacity is a prerequisite from a capability viewpoint (Suchomel et al., 2016). An athlete who does not possess the capacity to appropriately apply and absorb force will clearly be limited in their ability to execute COD tasks. As such, developing strength and speed-strength qualities is an important starting point for enhancing the ability to perform COD movements.

While clearly dependent upon the capacities and capabilities of the individual (which in turn are influenced by phenotype and training history), some guidelines can be offered with respect to programming. Table 2.2 offers some suggestions concerning exercise

selection for strength development. In general, a block of strength development will generally precede the introduction of other modes of training (i.e. plyometric and ballistic training) (Cormie et al., 2011; Haff & Nimphius, 2012; Stone et al., 2002; Suchomel et al., 2016). To increase force generation capacity and elicit the necessary baseline adaptation, it is recommended that conventional bilateral heavy resistance exercise is prioritised. An emphasis on this mode of training will facilitate overall strength gains via neuromuscular development (Cormie et al., 2011; Haff & Nimphius, 2012). Examples of these exercises are barbell back squat, barbell front squat and deadlift. The early emphasis of this mode of training will serve as a precursor for subsequent 'transfer training' used to augment specific capabilities for the COD task(s) (Cormie et al., 2011; Sale, 1988; Stone et al., 2002; Suchomel et al., 2016).

Developing trunk strength can be considered a goal throughout all stages of the training plan. In addition to concurrent trunk strength development provided by strength exercises detailed previously, the practitioner should also consider incorporating additional exercises that focus on isometric postural stability in the sagittal, transverse and frontal planes to further develop lumbopelvic muscle groups. Examples of exercises that accomplish this are front and side plank holds. Another mode of trunk exercise that should be considered are those that develop dynamic torque with a neutral spine. These exercises include single-leg supine bridge and woodchoppers.

Once requisite mechanical and physiological adaptation has occurred and an appropriate level of general strength has been attained, the emphasis should shift to unilateral strength (Cormie et al., 2011; Suchomel et al., 2016). While it is difficult to pinpoint a threshold to govern the shift in emphasis, consistency in correct posture and positioning during bilateral lifts with demanding loads is generally accepted as the means of 'readiness'. Examples of these exercises include barbell walking lunge and dumbbell lateral lunge. It is postulated that unilateral training modes are likely to afford superior transfer of strength gains to athletic movements such as COD activities due to greater dynamic correspondence (Brughelli et al., 2008; Gamble, 2011). During this stage in the training plan it is appropriate to introduce the first phase of COD training that has a focus on gross movement (discussed later) (Holmberg, 2009; Jeffreys, 2006).

Moreover, it is advised that practitioners be patient when using strength exercise to develop COD ability as it is suggested that long-term training (≥2 years) may be required before a beneficial transfer is observed (Keiner et al., 2014). Additionally, the level of growth and development (i.e. biological age) among athletes and its potential

impact on strength training should be considered as this may influence subsequent adaptation relative to performance in COD tasks (Condello et al., 2013; Jakovljevic et al., 2012; Vescovi & McGuigan, 2008; Yanci et al., 2014).

Table 2.1. Examples of general and sport-specific COD assessments.

Sport	General COD assessment	Specific COD assessment	Sport-specific task	Position
Football	Illinois test	3 m sprint, 90° cut, 6 m sprint, 30° cut, 5 m sprint	Give and go	Forwards
Rugby union	505 or modified 505	2 m sprint on a 10° angle, 90° cut, 7 m sprint	Receiving a set piece pass	Backs
American football	L-run	10 m sprint, 45° cut, 2 m sprint, 20° cut, 6 m sprint	Dig route	Receivers
Basketball	T-test	Jump-cut, 3 m curvilinear sprint, 180° turn to abrupt stop	Pick and roll	Guards
Tennis	9-6-3-6-9 test	90° turn, 4 m sprint, 140° cut, 1 m sprint, 45°cut, 6 m sprint	Volleying	N/A

Table 2.2. Exercise examples for developing strength for COD tasks with larger changes in velocity.

Bilateral/Phase I	Unilateral/Phase II	
Force Development		
Back squat	Barbell forward step-up	Rear-racked barbell forward walking lunge
Front squat	Barbell lateral step-up	Rear-racked barbell multidirectional lunge
Overhead squat	Front-racked barbell lateral step-up	Front-racked barbell forward walking lunge
		Front-racked multidirectional lunge
Straight-leg deadlift	Single-leg straight-leg deadlift	
Good morning	Single-leg good morning	
Overhead-loaded good morning	Overhead-loaded single-leg good morning	
Power Development		
Power clean	Barbell bound step-up	
Power snatch	Loaded jump squat	

Concerning jump performance, it is recommended that jump training be included in the training routine once athletes have developed an adequate amount of strength. While the optimal level of strength can be difficult to determine (Suchomel et al., 2016), the ability to back squat 1.7 to 2.0 times body mass is generally accepted as the threshold for maximising the benefits of jump training such as plyometric and ballistic training (Cormie et al., 2011; Haff & Nimphius, 2012; Stone et al., 2002; Suchomel et al., 2016). This is primarily due to research that demonstrates individuals who express lower-limb strength of this degree express higher magnitudes of power in various jumping activities than their weaker counterparts (Ruan & Li, 2010; Stone et al., 2002). Also, the neuromuscular benefits associated with the ability to back squat 2.0 times body mass apply to both male and female athletes (Haff & Nimphius, 2012). Athletes who cannot back squat 2.0 times body mass should not be totally excluded from jump training, however. Nonetheless similar to the recommended strength development progression, jump training, whether plyometric or ballistic, should begin with bilateral CMJ in the vertical direction (Table 2.3).

Next, bilateral movements should progress to multidirectional actions from a static start. Change of direction training during this stage should progress to tasks that require more direction changes and more variation in the angles of direction changes (Table 2.4). Following this stage, it is appropriate to incorporate accentuated jump training. The final progression would be to execute these movements in a unilateral fashion (Figure 2.2).

Next, it is appropriate to incorporate variations in constraints such as cuing initial movement, the nature of preliminary movement prior to the COD, the nature of the actual COD, and post COD task (Table 2.4) (Hoffman et al., 1996; Hori et al., 2008; Yanci et al., 2014). Practitioners should be aware of the potential influence straight-line speed may have on performance outcome especially when using time to completion as the measure of performance. It is recommended that an emphasis be placed on acceleration (e.g. 0-5 m and 0-10 m) training when aiming to enhance performance in COD tasks. Furthermore, it is appropriate to incorporate straight-line acceleration sprints that end with a ‘deceleration’ action due to this being considered an important component in COD activities (Hewit et al., 2011; Spiteri et al., 2013; Spiteri et al., 2015). This deceleration action should first be carried out over a given distance (e.g. 5 m sprint immediately followed by a 5 m deceleration), and gradually progress to a more abrupt stop (e.g. 5 m sprint to an immediate stop at the 5 m mark). The gradual

progression should be mediated primarily by proficient body segment positioning and joint angles. This approach will encourage more efficient modification of momentum (mass∆velocity), while simultaneously reducing the risk of injury (Holmberg, 2009; Jeffreys, 2006). The next step in training is to add variation to the direction the body will face following an abrupt stop while maintaining correct posture

Table 2.3. Exercise examples for developing jump ability for change of direction tasks with smaller changes in velocity.

Bilateral/Phase II*	Unilateral/Phase III**
Countermovement jumping (GCT > 0.25 s)	*Countermovement jumping (GCT > 0.25 s)*
Vertical jump	Vertical jump
Horizontal jump	Horizontal jump
Lateral jump	Lateral jump
Accentuated jumping (GCT < 0.25 s)	*Accentuated jumping (GCT < 0.25 s)*
Vertical drop jump†	Vertical drop jump†
Horizontal drop jump†	Horizontal drop jump†
	Lateral drop jump†
Horizontal jump to vertical jump	Horizontal jump to contralateral-leg vertical jump

Lateral jump to vertical jump	Lateral jump to contralateral-leg vertical jump
Horizontal jump to lateral jump	Horizontal jump to contralateral-leg lateral jump

*Done concurrent with Phase II of resistance training, **Done concurrent with Phase III of change of direction training;

GCT = ground contact time, † = Optimal drop height may need to be determined on an individual basis.

Table 2.4. Example of a change of direction training progression.

Phase I – Basic movement
Short distance accelerations with exaggerated deceleration action
Short distance accelerations with abrupt stop
Short distance accelerations with abrupt stop facing a different direction than the approach
Phase II – Intermediate movement
Short distance accelerations followed by a COD step with reacceleration in a new direction
Variation in the distance of approach acceleration and in the number of direction changes
Variation in the tasks post-COD step
Phase III – Advanced movement
Pre-planned movements that are sport-specific and position-specific
Variation in the constraints of the change of direction drill
Initiation of movement
Self-determined, reactive (audible/visual signal)
Nature of initial movement
Static start, running start, jumping start
Type of change of direction movement

Pre-planned, pre-planned with reactive movement (visual signal)

Sidestep, shuffle, backpedal

Environment of the change of direction drill

Total area and shape of the drill

Number of athletes participating

Types of athletes participating

Offense vs. offense/Defense vs. defense, Offense vs. defense

Sport-specific implements

Figure 2.2. Lateral jump to vertical jump and land.

(e.g. 5 m straight-line sprint followed by an abrupt stop with the final body position being perpendicular to the 5 m mark) (Figure 2.3).

The final stage in progression is to train multidirectional acceleration after the plant step of the abrupt stop. This would begin to address the multidirectional nature of movement experienced in most sports.

Figure 2.3. Forward sprint to an abrupt perpendicular stop.

Regarding technique training, research highlights specificity as the determinant of exercise selection. This is primarily due to the complex nature of motor skill development (Bloomfield et al., 2007; Holmberg, 2009; Jeffreys, 2006; Young & Farrow, 2013; Young et al., 2001). Therefore, the distinct components of movement that differentiate sports and respective positions should first be identified by the S&C coach via observation (e.g. video analysis) (Chaouachi et al., 2014; Cowley et al., 2006; Holmberg, 2009; Jeffreys, 2006; Young et al., 2001). Key characteristics that should be noted are the body positions the COD movements are executed from, preparatory pre-loading prior to the COD maneuver (e.g. fast vs. slow pre-loading), and the orientation of movement (e.g. pivot vs. shuffle). Additional considerations are the location of the center of mass, plant foot, and coordination within and between limbs (Havens & Sigward, 2015; Hewit et al., 2013; Sasaki et al., 2015; Sasaki, Nagano, Kaneko, Sakurai, & Fukubayashi, 2011). It is emphasised that the activity that precedes the COD maneuver influences each of these elements (Vanrenterghem et al., 2012; Young & Farrow, 2013). In a match context the athlete may be static or in motion, thus the initial velocity may fall within a broad range; equally the maneuver may be preceded by a

sprint or some form of jump. Such a range of starting conditions will govern what body position, foot placement and stride adjustments are appropriate for the COD movement that follows.

Once the practitioner identifies and categorises COD movement characteristics commonly experienced in the sport and at the respective position, COD tasks can be replicated in drills enabling specific instruction regarding the practice of technique (Holmberg, 2009; Jeffreys, 2006). For example, practice or competition video footage of a defensive lineman attacking the line of scrimmage is used for analysis. First, the lineman sprints 2 metres on a 60-degree angle to his right, then makes an abrupt 30-degree COD to his right, and sprints 3 m to disrupt the offensive backfield. This position-specific pre-planned movement can easily be replicated in training. Concerning training progression, technique training should begin with basic COD maneuvers, where skills are practiced with low contextual interference (e.g. a single task).

Figure 2.4. Lower contextual interference. American football position-specific COD drill.

Specific to the aforementioned example, this first entails practicing initiating rapid accelerations over 2 m from an angled three-point stance with ball movement (i.e. sport-specific cueing). Secondly, the abrupt 30-degree COD with an aggressive 3 m sprint is rehearsed. Once the athlete has mastered those sequences the progression to complex sports-specific tasks with higher contextual interference is warranted (i.e. several tasks) (Holmberg, 2009; Jeffreys, 2006; Young & Farrow, 2013). This could entail the addition of multiple athletes employing attacking and defending strategies as shown in Figure 2.5.

Figure 2.5. Higher contextual interference. American football position-specific COD drill.

Conclusion

Changing the direction of motion is a common requirement of most court- and field-based sports. Understandably, the ability to execute these actions as rapidly as possible is a desired characteristic highly regarded by coaches and athletes across a wide array of sports. Although there appears to be a significant association between strength, jump performance and COD capability, it is important to note these relationships may vary greatly as the magnitude of velocity (i.e. speed and direction) change varies. In general, tasks that require a large magnitude of velocity change (e.g. 180-degree COD task) will necessitate relatively higher levels of force production, while tasks that require smaller magnitudes of velocity change (e.g. 10-degree COD task) likely necessitate an optimal expression of strength. Other important factors to consider when assessing and training COD capabilities are biological and training age, type of sport and type of athlete (i.e. position-specific characteristics), as all have been demonstrated to influence performance in COD tasks.

Strength and jump training are considered key components in the development of COD ability. However, these two training modes seemingly have distinct roles in enhancing this athletic quality. The discrete contribution each mode of training will have with performance in COD tasks is driven by the magnitude of change in speed and direction a particular task requires. Due to these relationships, high-load and low-load strength and jump training are needed to improve COD ability. Also, it seems bilateral training should precede unilateral training, and consist of a progression from unidirectional

movements to multidirectional movements. Proper body and limb positioning and control should serve as indicators for progressing to more demanding tasks.

Training the technical aspects of COD tasks is complicated by the multitude of contributing factors to performance outcome. However, it appears that training COD technique should be centered around gross movement with an emphasis on position, placement and sequence. Pre-planned tasks that occur regularly within the sport should be specifically trained given these tasks will most likely be executed in competition.

Chapter 3 - The Relationship between Multidirectional Jumping and Performance in Change of Direction Tasks

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

Reference:

Bourgeois FA, Gamble PG, Gill ND, McGuigan MR. The relationship between multidirectional jumping and performance in change of direction tasks. *J Strength Cond* 32(3): 690-699, 2018.

Author contribution:

Bourgeois FA, 85%; Gamble PG, 5%, Gill ND, 5%; McGuigan MR, 5%.

Overview

Chapter 2 discussed potential factors that characterise COD tasks, and explored the relationship strength and speed-strength measures have with performance in COD tasks. The findings highlighted the task-specific nature of COD capabilities and emphasised the type of training used (i.e. strength vs. jump training) will facilitate distinct adaptation that will most likely be beneficial to specific tasks (e.g. 180-degree COD). Furthermore, the importance of familiarisation and reliability determination of selected measures was also underscored in Chapter 2. These conclusions led to the development of a multi-effort multidirectional jump (MDJ) task that may be used to assess and train COD capabilities. This manoeuvre was designed to replicate the rapid unilateral stretch-shortening cycle often associated with cutting tasks. This exercise also attempted to account for the individual differences associated with jumping by standardising the magnitude of accentuation according to right leg length. The purpose of this study was to determine the reliability of MDJ and COD measures, and quantify relationships between MDJ and COD measures. Secondly, the statistical power MDJ measures hold in predicting COD capabilities was explored.

Introduction

Field- and court-based sports require frequent, rapid anticipated and unanticipated direction changes during competition. Consequently, change of direction (COD) capabilities are considered essential for athletic success (Brughelli et al., 2008). Field-based COD assessments are also used for talent identification and selection (Robbins, 2010, 2012; Sheppard et al., 2014). Thus, the training and monitoring of COD capabilities are common foci in strength and conditioning programmes in field- and court-based sports. Given testing results will be used to regulate and modify short- and long-term training approaches to enhance COD capabilities pertinent to the sport, it is imperative the COD assessments selected by practitioners be practical and reliable.

Presently there are a multitude of tests used to evaluate COD capabilities, such as the 505, the pro agility test, the L-drill, the T-test, and the Illinois test (Brughelli et al., 2008; Stålbom, Holm, Cronin, & Keogh, 2007; Stewart et al., 2014). However, each assessment has distinct characteristics (e.g. total distance covered or the number of direction changes) that will emphasise specific biological and mechanical properties. For example, assessments that consist of extreme direction changes (e.g. a 180-degree COD) at full pace may be more reliant on strength capacity. As such, the specific associations between task and performance raises questions regarding the use of one assessment to profile the multi-faceted ability to change sprint direction. Recently, the efficacy of COD assessments that consist of longer distances has been challenged (Nimphius, Callaghan, Bezodis, & Lockie, 2017; Sasaki et al., 2011; Sayers, 2015; Zamparo et al., 2014). The authors noted the presence of bias towards high-speed linear running made it difficult to discern if the COD test was exclusively evaluating COD ability. In addition to assessing and monitoring performance in COD tasks, the ability to predict performance with the use of a simple task is also considered valuable by practitioners and sports scientists alike (Maulder & Cronin, 2005; Munro & Herrington, 2011). A practical yet reliable assessment with high predictive power may aide in talent identification and potentially afford time to conduct additional sport-related performance tests.

The reliability and practicality of jump tasks make jump tests attractive monitoring tools for strength and conditioning professionals (Claudino et al., 2016). Multidirectional jump (MDJ) ability has been demonstrated to successfully predict performance in certain COD tasks (Maulder & Cronin, 2005; Meylan et al., 2009). One contributing factor to this effectiveness is the relationship jumping has with other multi-joint athletic

tasks such as straight-line sprinting (Claudino et al., 2016). However, these reported jumps were executed from a static start, potentially affecting the relationship between jump task and COD task.

Considering these findings, the use of rapid accentuated jumping to assess performance in tasks requiring a COD at full pace appears logical. A popular jump task that involves rapid accentuation of the musculature is the DJ (Iacono, Martone, Milic, & Padulo; Matic et al., 2015; Ruan & Li, 2008). However, optimal drop height has been demonstrated to be individual-specific (Matic et al., 2015), making the acquisition of appropriate boxes and individual testing potentially expensive and impractical. A more feasible approach may be needed to replicate the rapid eccentric-phase accentuation of the stretch-shortening cycle (SSC) associated with a DJ. A task that includes horizontal movement immediately preceding a CMJ may provide a more practical method of administering the desired rapid eccentric-phase accentuation. Previous research has investigated the effects of completing a horizontal jump before executing a 45-degree or 90-degree COD task (Serpell, Ball, Scarvell, Buttfield, & Smith, 2014). However, the horizontal jumps that preceded the COD task were fixed to absolute distances that were relatively short, potentially preventing optimal accentuation. Recently a lateral jump with the landing distance set relative to body height was examined (Inaba, Yoshioka, Iida, Hay, & Fukashiro, 2013). A jump task that combines these two components (sequential horizontal jumping involving a direction change, and adjusting the initial jump distance to individual anthropometrics) appears to be appropriate for assessing and training performance in COD tasks, most notably 45-degree cutting tasks.

Therefore, the practical question of this study was “Can multidirectional jump tasks relative to leg-length be used to train and monitor performance in COD tasks in male athletes?” The primary objective of this study was to determine the between- and within-session reliability of three MDJ and two COD tasks in a male cohort. The second objective was to examine correlation between the MDJ and COD tasks. It was hypothesised the relationship between MDJ performance and COD performance would strengthen as approach jump distance in the MDJ increased; the MDJ task would have stronger statistical association with the 45-degree COD task than the 180-degree COD task; and the MDJ assessments would possess more predictive power for 45-degree COD performance than for 180-degree COD performance.

Methods

Experimental approach to the problem

Between-session and within-session experimental designs were used to determine the reliability of the MDJ and COD tests. Test-retest reliability was determined by having participants perform the MDJ and COD tasks at two different time periods: Session one (test) and Session two (retest one week later). Prior to Sessions one and two, participants completed two one-hour familiarisation sessions separated by 24 hours. It should be noted that each familiarisation and testing session was performed during the same time of day to control for diurnal effects (Teo, Newton, & McGuigan, 2011).

Subjects

Twenty males (age: 27.5 ± 5.9 yr; body mass: 79.2 ± 11.8 kg; height: 1.8 ± 0.1 m; leg length: 0.85 ± 0.04 m) participated in the study. The cohort comprised team-sport (n = 15) and individual-sport (n = 5) athletes. The volunteers were from a wide array of sports which consisted of rugby union, rugby league, American football, football, basketball, cricket, athletics and weightlifting. There were three nationally competitive participants, three provincially competitive participants and six club-level competitors. Training status criterion was a minimum of one hour of systematic resistance and conditioning training at least three days·week^{-1} (Baechle & Earle, 2008). All volunteers were also required to have a minimum of one year of systematic physical training. Each participant had the benefits and risks of the investigation explained to them verbally and in written form, and signed an informed consent before participation. The Auckland University of Technology Ethics Committee approved all procedures undertaken in this study (15/322).

Procedures

All participants were instructed to refrain from unaccustomed or vigorous activity (e.g. 1-RM testing) 48 hours prior to testing; however, volunteers continued usual training and activities. This was done to control sudden changes in physical activity which can influence performance and reliability. First, anthropometry (height, weight and right-leg length) were measured. Second, assessment and plant-leg order were randomised and counterbalanced. That is, the sequence of tests and the leg to ultimately serve as the ‘change of direction limb’ were selected and ordered by blinded drawing. This method was used to control order effects. Next, two familiarisation sessions, separated by 24-

hours, were conducted which included a standardised warm-up and identical tests described below, in the same order. The warm-up consisted of five minutes of submaximal jogging followed by five minutes of multi-joint dynamic stretches. Twenty-four hours after the second familiarisation experimental testing began using identical protocols. While participants were instructed to perform all familiarisation and testing tasks with maximum effort, neither verbal encouragement nor technical cueing were given as this may influence results (Khuu, Musalem, & Beach, 2015). Also, all participants wore similar athletic clothing (e.g. t-shirt and shorts) and the same athletic shoes for all familiarisation and testing sessions. To further reduce measurement variance, all procedures were done by the same researcher.

Anthropometrics

Body mass and height were measured using a calibrated digital scale (HW-200KGL, A & D, CA, USA) and stadiometer (Holtain limited, Harpenden, Wales, UK), respectively. Next, using a previously described method (Mirwald, Baxter-Jones, Bailey, & Beunen, 2002), leg length was measured on the right leg from the greater trochanter to the lateral malleolus with a measuring tape and used to calculate 1.5 and 2.5 times leg lengths. All leg lengths were rounded to the nearest centimetre.

Change of direction assessment

Change of direction performance in left- and right-plant leg tasks that require large and more modest direction changes were assessed using a 180-degree and a 45-degree manoeuvre, respectively (Figure 3.1). To eliminate the influence of reaction time on total sprint time participants began each trial at their own volition. Five attempts per assessment were given for both left- and right-plant legs with approximately two min rest between each trial. The contact zone for all attempts was marked with tape to increase consistency in foot placement during the plant-step. Both COD contact zones were selected due to the average touchdown position of the plant foot during pilot testing. Successful trial criteria were: maximum effort throughout the test, sprinting within the designated 1.20 m path; foot contact within the designated contact zone; and effort given to total trial time rather than plant-step placement.

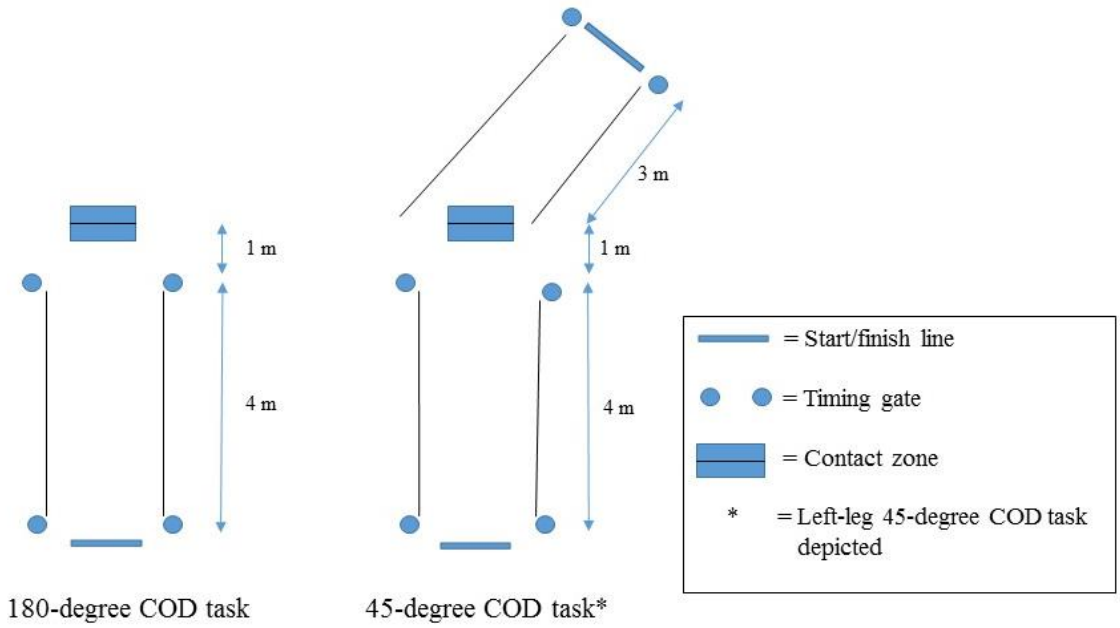

Figure 3.1. Change of direction (COD) assessments

A modified 505 was used to measure 180-degree COD performance (Sasaki et al., 2011). This assessment was selected for two practical concerns. First, it required less space to conduct testing. Settings that lack space with relatively unchanging conditions (e.g. indoor facility) cannot accommodate tests that require large amounts of space (e.g. 5 m vs. 15 m). The shorter distance required also affords a reduction in injury risk due to less time to increase momentum. Second, the 180-degree COD task was selected based upon previous investigations demonstrating value in this COD task in relation to contact team sports (Gabbett, 2009). More important this test served as the COD manoeuvre that required a larger magnitude of direction change (i.e. 180-degree angle change). Participants began 30 cm behind the start line in a two-point staggered position with the non-plant leg as the lead leg. At their volition participants sprinted forwards, then executed a 180-degree turn in the 0.15 m × 0.60 m contact zone, before sprinting back in the opposite direction through the start/finish line.

The second COD assessment was a 45-degree cutting task. This test also served as a COD measure that is more specific to attacking manoeuvres in team sports (Serpell et al., 2014). Most importantly, this test served as the COD task that required a more modest direction change (i.e. 45-degree angle change). As with the 180-degree task the participant began in a staggered stance. At their volition participants sprinted forwards, executed a 45-degree direction change (placing the respective foot within the 0.30 m ×

0.60 m contact zone), then sprinted through the finish gate. Start stance was identical to that of the 180-degree COD task. A goniometer and tape were used to mark the sprint path after the plant-step.

A high-speed digital camera (Casio, Exilim EX-FH20, Tokyo, Japan) and timing lights (Speed Light V2 gate, Swift, Wacoi, QLD, Australia) were used to monitor trial quality and measure sprint times of each assessment, respectively. Variables of interest were approach times (i.e. sprint time prior to the COD-step), exit times (i.e. sprint time after the COD-step) and total time.

Multidirectional jump assessment

The MDJ task is a modification of previously reported protocols (Inaba et al., 2013; Ruan & Li, 2008; Serpell et al., 2014) (Figure 3.2). Participants began in a bilateral stance facing the single-leg landing point located in a 0.30 m × 0.60 m contact area.

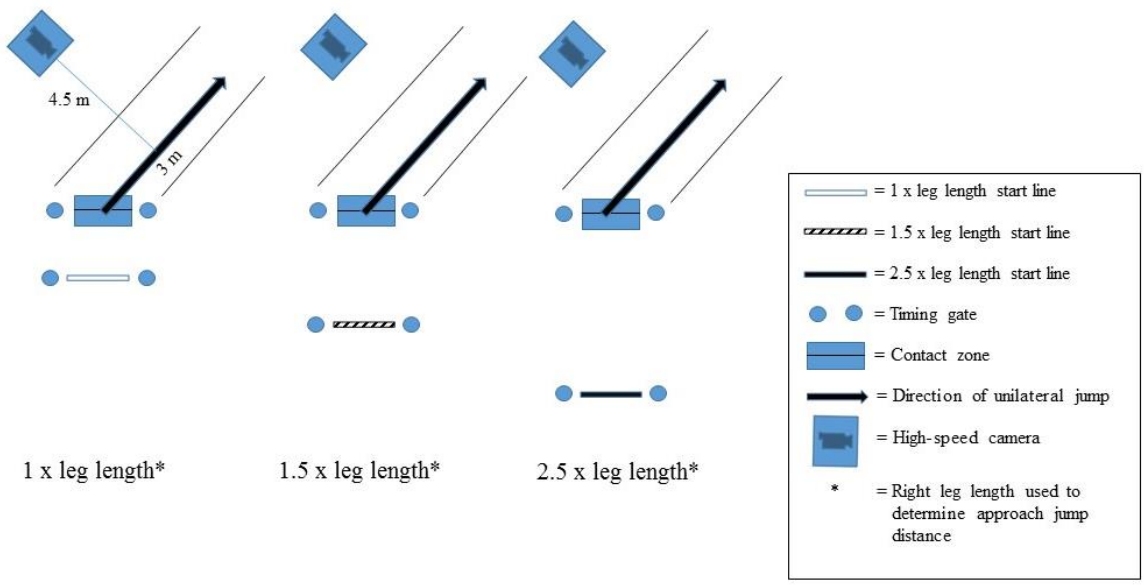

Figure 3.2. Multidirectional jump (MDJ) assessments

When ready participants executed a bilateral horizontal jump, made ground contact with a single leg, immediately jumped 45 degrees to the contralateral side, then landed on two feet while simultaneously facing the new direction. Distances of the approach jump towards the contact area were equal to 1, 1.5 and 2.5 × leg-length with tape marking the respective start point. Leg-length was used to individualise the jump task due to previous demonstrations of mechanical output being influenced by preliminary movement (Ruan & Li, 2008). Participants were required to demonstrate postural control throughout the attempt, and land on both feet. If not accomplished, another attempt was given. No preparatory step in the first bilateral jump was allowed, however, no restrictions were placed on the swing of the arms or the contralateral leg. Participants were given five attempts from 1, 1.5 and 2.5 × leg-length approach distances where the left and right legs each served as the unilateral jump leg with 1 min rest between each trial. Timing gates (Speed Light V2 gate, Swift, Wacol, QLD, Australia) were used to measure the time to complete the approach jump by placing a gate at the start line of the approach jump and a gate at the centre of the designated single-leg contact area. A high-speed digital camera (Casio, Exilim EX-FH20, Tokyo, Japan) was used to assess the quality and distance of each jump. The camera was placed 4.5 m perpendicular to a 45-degree line that extended 3 m from the centre of the contact area. Distance of the unilateral jump (i.e. the second jump) was calculated by importing the video captured at 120 frames·s^{-1} into a kinematic analysis software (Kinovea, version 0.8.15). The toe at

first touchdown and heel at second touchdown of the jump-leg served as the measurement points. The software was calibrated using a 1 m marking that was parallel to the 45-degree single-leg jump path. Variables of interest were time to complete the approach jump and single-leg jump distance.

Statistical analysis

Using previously reported data (Oliver & Meyers, 2009) sample size estimation was calculated *a priori* using commercially available software (G*Power, version 3.0.10). The reliability coefficient and effect size were set to 0.75 and 0.4, respectively, and yielded a sample size estimation of 18 total participants.

The central tendency and dispersion of the data were calculated for all variables as mean ± SD with 90% confidence limits (90%CL) and used for analysis. All data were log transformed to reduce non-uniformity of error (Hopkins, Marshall, Batterham, & Hanin, 2009; Hopkins, 2000). Paired samples *t*-tests were run in a commercially available statistics software program (version 22.0, SPSS Inc., Chicago, IL, USA) to identify systematic bias between-sessions (Hopkins et al., 2009). Changes in test-retest scores were standardised by dividing the change in mean (CIM) by the Session one between-participant SD to assess the standardised CIM (SCIM). Thresholds of 0.2, 0.6, 1.2 and 2.0 were used for magnitudes of small, moderate, large, and very large, respectively (Hopkins et al., 2009). Intraclass correlation coefficients (ICC 3,1) for each variable were derived from Session one and Session two scores to calculate between-session reliability that are unbiased for any sample size (Hopkins, 2000). Specifically, the participants and the trials were treated as a random effect and a fixed effect, respectively. Typical error of measurement was used to express variability as a percentage of the mean for between-session scores (CV).

Within-session reliability was evaluated via between-trial percent CIM and ICC. To further assess measurement precision, between-trial CV was also examined. The smallest worthwhile change (SWC) was determined by multiplying the between-participant SD by 0.5. Between-participant SD was multiplied by 0.5 to generate a more conservative threshold. Lastly, the assessment was deemed very useful, useful or less useful if SWC > CV, SWC = CV and SWC < CV, respectively (Düking, Born, & Sperlich, 2016).

The predictive ability of MDJ performance was assessed via bivariate regression analysis. For all measurements, the histogram, normal probability-probability plot, and

scatterplot were first inspected to determine the distribution of standardised residuals, the linearity between observed and predicted data, and homoscedasticity, respectively. Variables of interest were interclass correlation (r), adjusted coefficient of determination (r^2) and standard error of the estimate (SEE).

Results

Between-session reliability

Table 3.1 shows between-session CIM with associated levels of significance (*p* value) and SCIM for the COD tasks. All 180-degree COD measures showed no significant between-session change except for LT180 and RT180 approach sprint times. For 45-degree COD measures, three measures showed no significant change while LT45 approach sprint time, LT45 exit sprint time and RT45 approach sprint time showed significant change. Between-session Pearson's correlation coefficient (r) for LT- and RT180 COD measures were 0.698 to 0.906.

Table 3.1. Between-session reliability statistics for change of direction measures.

Measure	Test	Retest	CIM	*p*-value	SCIM	Magnitude	CV
LT180 approach time (s)	1.11 ± 0.05	1.14 ± 0.06	0.03	0.00‡	0.58	Small	2.5
LT180 exit time (s)	1.08 ± 0.05	1.07 ± 0.07	-0.01	0.53	-0.13	Trivial	3.3
LT180 total time (s)	2.72 ± 0.10	2.74 ± 0.13	0.02	0.18	0.20	Trivial	1.6
RT180 approach time (s)	1.10 ± 0.06	1.12 ± 0.06	0.03	0.00‡	0.58	Small	3.2
RT180 exit time (s)	1.06 ± 0.07	1.07 ± 0.07	0.01	0.28	0.14	Trivial	2.7
RT180 total time (s)	2.72 ± 0.08	2.73 ± 0.12	0.01	0.53	0.06	Trivial	1.5
LT45 approach time (s)	0.99 ± 0.05	1.02 ± 0.06	0.03	0.00‡	0.57	Small	2.6
LT45 exit time (s)	0.72 ± 0.07	0.70 ± 0.07	-0.02	0.01†	-0.28	Small	3.4
LT45 total time (s)	1.71 ± 0.10	1.71 ± 0.11	0.01	0.58	0.08	Trivial	2.3
RT45 approach time (s)	0.99 ± 0.08	1.02 ± 0.07	0.02	0.01†	0.28	Small	2.5
RT45 exit time (s)	0.71 ± 0.06	0.70 ± 0.07	-0.01	0.05	-0.16	Trivial	2.5
RT45 total time (s)	1.71 ± 0.12	1.72 ± 0.10	0.01	0.25	0.10	Trivial	1.8

LT = left plant-leg, RT = right plant-leg, 45 = 45-degree change of direction task, 180 = 180-degree change of direction task, CIM = change in mean, SCIM = standardised change in mean, *p* value = *t*-test significance, † = significant, $p \leq 0.05$, ‡ = significant, $p \leq 0.01$, CV = percentage of coefficient of variation.

Intraclass correlation coefficients for these measures were 0.813 to 0.948. Pearson's r for LT and RT45 COD measures were 0.822 to 0.933. Intraclass correlation coefficients for these measures were 0.845 to 0.960.

Approach time for LT MDJ at 2.5 × leg length was the only MDJ that showed a significant change (Table 3.2).

Table 3.2. Between-session reliability statistics for multidirectional jump measures.

Measure	Test	Retest	CIM	*p*-value	SCIM	Magnitude	CV
LT1 approach time (s)	0.71 ± 0.19	0.69 ± 0.19	-0.02	0.42	-0.11	Trivial	17.5
LT1.5 approach time (s)	0.80 ± 0.14	0.80 ± 0.17	0.01	0.92	0.05	Trivial	18.3
LT2.5 approach time (s)	1.05 ± 0.17	1.16 ± 0.30	0.11	0.03†	0.80	Moderate	18.8
LT1 distance (m)	2.08 ± 0.30	2.06 ± 0.32	-0.03	0.28	-0.001	Trivial	3.6
LT1.5 distance (m)	2.17 ± 0.35	2.14 ± 0.37	-0.04	0.29	-0.001	Trivial	4.0
LT2.5 distance (m)	2.25 ± 0.32	2.23 ± 0.35	-0.03	0.25	0.001	Trivial	3.0
RT1 approach time (s)	0.73 ± 0.17	0.74 ± 0.29	0.01	0.79	0.06	Trivial	21.4
RT1.5 approach time (s)	0.82 ± 0.16	0.83 ± 0.25	0.01	0.90	0.43	Small	19.2
RT2.5 approach time (s)	1.04 ± 0.22	1.13 ± 0.27	0.09	0.06	-0.001	Trivial	12.8
RT1 distance (m)	1.95 ± 0.32	1.93 ± 0.33	-0.03	0.24	-0.001	Trivial	3.4
RT1.5 distance (m)	2.04 ± 0.32	2.01 ± 0.37	-0.04	0.18	-0.001	Trivial	4.3
RT2.5 distance (m)	2.12 ± 0.31	2.09 ± 0.34	-0.04	0.13	-0.001	Trivial	3.2

LT = left plant-leg, RT = right plant-leg, 1 = 1 × leg length, 1.5 = 1.5 × leg length, 2.5 = 2.5 × leg length,

CIM = change in mean, SCIM = standardised change in mean, *p* value = *t*-test significance,

† = significant, $p \leq 0.05$, ‡ = significant, $p \leq 0.01$, CV = percentage of coefficient of variation.

Between-session Pearson's r for the approach jump times were 0.629 to 0.792. Intraclass correlation coefficients for these measures were 0.751 to 0.868. Between-session Pearson's r for jump distances were 0.940 to 0.967, while ICC were 0.968 to 0.980.

Within-session reliability

LT180 exit sprint time showed the highest CIM, the highest TE and the lowest ICC. Similarly, RT180 exit sprint time had the highest CIM and the highest TE, while RT180 approach sprint time had the lowest ICC.

LT45 exit sprint time had the highest CIM, while LT45 approach sprint time showed the highest TE and the lowest ICC. Regarding RT45 measures, RT45 approach sprint time possessed the highest CIM, the highest TE, and lowest ICC.

Left-leg MDJ approach jump time for 1 × leg-length showed the highest CIM and the lowest ICC, while that for 2.5 × leg-length showed the highest TE. Concerning left-leg jump distance, 1 × leg-length showed the highest CIM, the highest TE and the lowest ICC. Right-leg MDJ approach jump time for 1 × leg-length showed the highest CIM, the highest TE and the lowest ICC. Similarly, right-leg 1.5 × leg-length jump distance showed the highest CIM, while that for 2.5 × leg-length jump distance showed the highest TE and the lowest ICC.

All COD and MDJ measures were found to be very useful (Tables 3.3 and 3.4, respectively).

Table 3.3. Usefulness of change of direction measures in detecting the smallest worthwhile change in performance.

Measurement	SWC	90%CL lower and upper		TE	90%CL lower and upper	
LT180 approach time (s)	1.12	0.89	1.54	0.02	0.02	0.03
LT180 exit time (s)	1.34	1.06	1.84	0.04	0.04	0.05
LT180 total time (s)	0.91	0.72	1.24	0.01	0.01	0.01
RT180 approach time (s)	1.20	0.91	1.58	0.00	0.02	0.03
RT180 exit time (s)	1.50	1.18	2.04	0.00	0.03	0.04
RT180 total time (s)	0.94	0.74	1.29	0.02	0.01	0.02
LT45 approach time (s)	1.20	0.95	1.65	0.03	0.02	0.03
LT45 exit time (s)	1.96	1.55	2.69	0.03	0.02	0.03
LT45 total time (s)	1.23	0.98	1.69	0.02	0.02	0.02
RT45 approach time (s)	1.49	1.18	2.05	0.03	0.02	0.03
RT45 exit time (s)	1.83	1.45	2.52	0.02	0.02	0.03
RT45 total time (s)	1.33	1.06	1.83	0.02	0.02	0.02

LT = left plant-leg, RT = right plant-leg, 45 = 45-degree change of direction task, 180 = 180-degree change of direction task.

SWC = smallest worthwhile percent change, 90%CL lower and upper = lower and upper 90% confidence limits, TE = percentage of typical error.

Table 3.4. Usefulness of multidirectional jump measures in detecting the smallest worthwhile change in performance.

Measurement	SWC	90%CL lower and upper		TE	90%CL lower and upper	
LT1 approach time (s)	4.87	3.85	6.74	0.11	0.10	0.14
LT1.5 approach time (s)	3.88	3.07	5.35	0.09	0.08	0.10
LT2.5 approach time (s)	4.52	3.57	6.25	0.11	0.09	0.13
LT1 distance (m)	5.76	4.55	7.98	0.18	0.15	0.21
LT1.5 distance (m)	4.77	3.77	6.60	0.12	0.10	0.14
LT2.5 distance (m)	4.75	3.75	6.57	0.13	0.12	0.16
RT1 approach time (s)	3.29	2.60	4.53	0.03	0.03	0.04
RT1.5 approach time (s)	3.70	2.93	5.11	0.03	0.03	0.04
RT2.5 approach time (s)	4.52	3.57	6.25	0.03	0.02	0.03
RT1 distance (m)	3.72	2.94	5.13	0.04	0.03	0.04
RT1.5 distance (m)	3.75	2.96	5.17	0.03	0.03	0.03
RT2.5 distance (m)	3.40	2.69	4.69	0.04	0.03	0.04

LT = left plant-leg, RT = right plant-leg, 1 = 1 × leg length, 1.5 = 1.5 × leg length, 2.5 = 2.5 × leg length, SWC = smallest worthwhile percent change, 90%CL lower and upper = lower and upper 90% confidence limits, TE = typical error.

Regression analysis

All MDJ distances explained variation for 180-degree and 45-degree COD performance. All SEE were low (SEE = 0.01 to 0.02). Statistical significance was found for regression equations using 1, 1.5 and 2.5 × leg-length jump distances to predict left- and right-leg 180-degree COD total sprint times (p = 0.001) and right-leg 45-degree COD total sprint times (p = 0.013 to 0.024).

Discussion

The purpose of this study was to determine the between-session and within-session reliability of performance measures associated with two COD tests and three MDJ tests. Major findings of the current investigation are: 1) all measures, but one, displayed high between-session reliability; 2) 21 out of 24 measures displayed high within-session reliability; 3) MDJ distances were successful in predicting performance in ipsilateral COD tasks; and 4) sufficient familiarisation of MDJ and COD assessments may be required to obtain reliable data.

Between-session reliability

It appears two familiarisation sessions and two-maximal effort familiarisation trials during testing sessions attenuated significant systematic bias within measurements. Similarly, despite five measures displaying a statistically significant CIM between-sessions, further inspection revealed only one measure (i.e. LT25 approach time, p = 0.026, ES = moderate) showed a SCIM greater than a small CIM. It is suspected these measures would show less of a change between sessions in a more homogeneous group that frequently execute COD tasks in their sport.

All COD total sprint times displayed between-session reliability. However, approach and exit sprint times generated unstable between-session reliability within this cohort. Total sprint times for 180-degree COD tasks of the present study were similar to or slower than those reported for the traditional and modified 505 tests (Gabbett, 2009; Sasaki et al., 2011; Stålbom et al., 2007). Nonetheless, between-session reliability of the 180-degree COD test in the current study maintained values similar to previous reports (Gabbett, 2009; Stålbom et al., 2007). Similarly, total times for the 45-degree COD test of the current study were faster than those of previous reports (Oliver & Meyers, 2009), and maintained between-session reliability (Oliver & Meyers, 2009).

All approach jump times possessed reliable ICC mean values. However, the estimate of the true reliability score was deemed unstable due to all lower 90%CL extending below 0.75 within this group. Though there is limited data examining the time to complete the initial jump during multi-effort horizontal jumping, between-session ICC of horizontal jump tasks appear to be lower when the test objective is time to completion compared to the objective of maximal jump distance (Bolgla & Keskula, 1997; Booher, Hench, Worrell, & Stikeleather, 1993; Johnsen, Eitzen, Moksnes, & Risberg, 2015; Ross, Langford, & Whelan, 2002). This association is further supported by recent research investigating identical tasks in a male sub-group (Ross et al., 2002), where the hop for time possessed a lower ICC when compared to the hop for distance (ICC = 0.60 vs. 0.80, respectively). The variability observed in the time measurement could be influenced by the complexity of the task (Munro & Herrington, 2011) or unfamiliarity of the controlled situation/environment (Hopkins, Schabort, & Hawley, 2001).

All jump distances demonstrated between-session reliability. This is in agreement with previous reports of single-effort unilateral horizontal CMJ tasks possessing ICC and TE with ranges of 0.80 to 0.96 and 1.9 to 5.0%, respectively (Bolgla & Keskula, 1997; Markovic, Dizdar, Jukic, & Cardinale, 2004; Maulder & Cronin, 2005; Sierer et al., 2008; Stålbom et al., 2007). The high between-session reliability and low TE of the jump distances are also in agreement with previous reports examining multi-effort horizontal jumping tasks (Bolgla & Keskula, 1997; Johnsen et al., 2015; Markovic et al., 2004; Maulder & Cronin, 2005). Similar to the present study, Simpson and co-workers (2006) examined multi-effort single-leg accentuated horizontal jump ability with distances of the approach jump set to 80, 120 and 160% of leg length in a cohort of female athletes. Between-session reliability were found in all three tasks (CIM = -0.92 to 5.16%; ICC = 0.82 to 0.89) (Simpson & Cronin, 2006).

Within-session reliability

High within-session reliability was found for all COD total time measurements. However, approach and exit times of both the 180-degree and 45-degree COD tasks were the second most unstable measurements of the current study. The right-leg 45-degree COD sprint times were the most reliable COD measures with only two between-trial approach sprint times possessing an ICC with a lower 90%CL extending below 0.75. The discrepancy between 180-degree and 45-degree COD measurements is most likely associated with the magnitude of direction change involved. The angle of

direction change has been shown to influence performance outcome (Young et al., 2002), and has been attributed to different mechanical determinants that underpin each task (Spiteri et al., 2015). Tasks that call for a relatively smaller angle of direction change, which require a relatively smaller change in velocity, have been proposed to be more reliant on speed qualities, such as the rate of force development (RFD) (Sheppard et al., 2014; Suchomel et al., 2016; Young et al., 2001). Conversely, tasks that require a relatively larger angle of direction change, which require a relatively larger change in velocity, have been proposed to be more reliant on strength capacity (Spiteri et al., 2015; Suchomel et al., 2016).

The precision of the estimate of change between-trials was investigated by examining the CIM and CV of consecutive pairs of trials (Hopkins, 2000). Specifically, approach and exit sprint times of each COD task displayed larger between-trial variation when compared to the total sprint time of each COD task. Relative to the current sample of volunteers it can be assumed that several participants may have been unaccustomed to highly controlled sprints with a COD due to their sport (i.e. 100-m sprinter). This unfamiliarity would generate greater variation in approach and exit strategies with each attempt. Another assumption would be the average participant lacked the necessary strength to execute the transition from approach to exit in a consistent manner. *Post-hoc* inspection of the high-speed video suggested high within- and between-participant variation in selecting approach and exit paths, braking strategy (e.g. position and placement of the penultimate step), and flexion and extension of the trunk, hip and knee between trials. Though these observations are speculative, previous research has demonstrated several factors such as kinematic modifications (Sasaki et al., 2011), vertical stiffness (Serpell et al., 2014) and strength capacity (Spiteri et al., 2015) to have association with performance outcome.

Within-session ICC for all approach jump time measures of the current study possessed an ICC with a lower 90%CL that extended below 0.75. Although there is a paucity of data examining time to complete a multi-effort jump, the relative instability of the approach jump time may reflect the findings of previous investigations (Booher et al., 1993; Qiao, Brown, & Jindrich, 2014). Booher and co-workers (1993) showed the time to complete repetitive unilateral horizontal hopping tasks possessed lower within-session ICC than the single-effort unilateral task examined (ICC = 0.77 vs. 0.97, respectively) (Booher et al., 1993). Furthermore, Qiao and colleagues (2014) noted that variability within a task may be influenced by the ability to modulate factors during the

execution (Qiao et al., 2014). *Post-hoc* inspection of the high-speed video supports this proposal as participants appeared to adjust global and segmental posture, position and sequence from trial to trial in an effort to optimise performance outcome. Though these observations require kinematic evaluation, previous research has demonstrated performance outcome to have an association with kinesthesia (Massion, 1992), and subsequent neuromuscular modification (Serpell et al., 2014).

In contrast, jump distance for each leg length and for each leg were the most reliable measurements of the current study with all measurements possessing excellent between-trial ICC. The within-session reliability of the jump distances of the current study are in agreement with previous reports investigating single-leg horizontal jump ability. Bolgla and colleagues (1997) found two multi-effort single-leg horizontal tasks to be reliable with no significant change observed from the first trial to the sixth trial ($F = 2.1$ and 1.6, $p \geq 0.05$). Similarly, Markovic and colleagues (2004) found similar within-session reliability for a single-leg triple jump in a cohort of physically active college-aged volunteers (ICC = 0.93; TE = 2.9%). As proposed earlier, the variability within the measure of jump distance is most likely due to unique spatial and temporal feedforward/feedback and accompanying kinematic adjustments within each attempt.

Further inspection of between-trial reliability for the COD and MDJ tasks revealed an overall positive trend from trial one to trial five. Specifically, when all between-trial ICC with 90%CL below 0.75 were tallied, trial 1-2, trial 2-3, trial 3-4 and trial 4-5 each possessed 12, 12, 10 and 8, respectively. This would suggest measurements became more stable with each attempt. Therefore, it is suggested that an additional maximal effort familiarisation trial (three total) with two to three test trials be used to attain reliable data when using the assessments of the present study. This observation is in agreement with previous suggestions of executing maximal effort attempts prior to testing to attenuate any systematic change (Markovic et al., 2004; Stålbom et al., 2007).

Usefulness

The very useful ratings suggest all COD and MDJ assessments of the present study are capable of detecting the SWC in respective measures. Due to previous recommendations, the CV of each measure was doubled for comparison with the SWC (Smith & Hopkins, 2011) *post-hoc*. This similarly rated all measures as very useful. However, caution should be exercised when using jump approach times as these were the least reliable measures. Nonetheless it can be said with confidence that the COD

times and MDJ distances are sufficient for detecting changes in task-specific performance following intervention. More research is needed to explore the usefulness of these assessments in a more homologous sample, as homogeneity has been shown to decrease the amount of variation (i.e. SD) in a group thus decreasing the SWC threshold (Hopkins, 2000).

Regression analysis

Predicting in-play athletic performance is a topic of interest among coaches and sport scientists (Maulder & Cronin, 2005). Therefore, the ability to use the MDJ task as a means of predicting performance in 180-degree and 45-degree COD tasks was explored. Although there were 8 out of 12 instances MDJ distances possessed significantly large correlation with ipsilateral COD performance, MDJ distance explained a greater proportion of variance in 180-degree COD performance compared to that of 45-degree COD performance. This was unexpected due to the MDJ tasks involving a more similar movement pattern to the 45-degree COD manoeuvre than the 180-degree COD manoeuvre. Also unexpected was the left- and right-leg MDJ relative to 1 × leg-length explaining more variance in 45-degree COD performance than the MDJ relative to 1.5 and 2.5 × leg-lengths. These findings suggest the MDJ executed from 1 × leg-length may emphasise more similar neuromuscular and musculotendinous characteristics as the 45-degree COD test. More research is needed to further elucidate relationships that underpin these observations.

Also unexpected was MDJ distance presenting significantly greater predictive power for 180-degree COD performance than 45-degree COD performance within a sample size of 20 participants. When data were simulated *post-hoc* to explore predictive power in a larger group (n = 100), the ability of all MDJ distances (1, 1.5, and 2.5 × leg-lengths) to predict 45-degree COD performance were statistically almost certain (i.e. $p \leq 0.0001$). More research is needed in understanding the factors underpinning both the COD and MDJ assessments, as well as exploring the predictive strength of the MDJ in a larger, more homogeneous group.

It is acknowledged that there are limitations to the current study. First, the results attained from this study are only applicable to the participants sampled in the present study. More homogeneous groups may generate dissimilar statistics than those found in the heterogeneous group examined. This posit is primarily due to reports of ICC being sensitive to between-participant SD (Hopkins, 2000). Therefore, examination of COD

and MDJ measures in more homologous groups is warranted. Second, the test-retest reliability of these assessments are only applicable to measurements taken 7 days from one another following two familiarisation sessions. Lastly, the findings of the present study are limited to the specific tasks of the study (i.e. 180-degree and 45-degree COD tasks) and should not be generalised to describe overall COD performance.

Practical Applications

The most important practical finding of this study is the high correlation observed between COD and MDJ measures. Large association between these measures suggests the MDJ can be used as a training tool to increase performance in COD tasks. Jump distance following an approach jump relative to 1 × leg-length appears to be a better predictor of overall 180-degree and 45-degree COD performance. The use of MDJ as a training tool can provide individual-specific neuromotor overload that corresponds with athletic manoeuvres experienced in competition. Additionally, the use of individual leg-length also makes the MDJ a practical tool. Instead of specialised equipment, the practitioner only needs measuring and marking tape. This is also useful to practitioners that have limited time with their athletes. For example, coaches may seek to use the MDJ assessment relative to 1 × leg-length to accurately estimate performance in 180-degree and 45-degree COD tasks, potentially reducing the total time of the testing session. Regarding performance monitoring, the high reliability observed in COD and MDJ measures in this study suggests these measures can be used to evaluate and track performance differences in 180-degree and 45-degree COD tasks. Practitioners are advised to consider training age and type of athlete when determining familiarisation procedures to increase the likelihood of attaining reliable data. Also, the low within-individual variation following sufficient familiarisation suggests only two to three testing measures are needed to quantify true performance score estimates for the individuals to be tested.

Chapter 4 - The Relationship between Multidirectional Jumping and Performance in Change of Direction Tasks: A Kinetic Analysis

Overview

In Chapter 2 the association between physical characteristics and performance in COD tasks was reviewed. The review provided evidence-based training considerations when seeking to enhance performance in COD tasks. Next, Chapter 3 explored the reliability of 180-degree and 45-degree COD tasks and individualised MDJ tasks, in addition to investigating statistical association between tasks. The reliability and correlation established between MDJ tasks and 180-degree and 45-degree COD tasks supported using these assessments to differentiate individuals. Additionally, the observed relationships in Chapter 3 provided a rationale for using MDJ tasks to improve 180-degree and 45-degree COD performance. To further investigate performance determinants that distinguish faster and slower individuals, the primary aim of this study was to explore plant-step kinetics of MDJ and COD tasks, and the relationship plant-step kinetics have with MDJ distances and COD total sprint times. Identifying MDJ mechanical performance variables associated with distinguishing faster and slower individuals would have practical significance.

Introduction

Change of direction capabilities, whether anticipated or unanticipated, are considered essential for success in team sports, such as soccer (Chaouachi et al., 2012), rugby codes (Delaney et al., 2015), American football (Lockie, Stone, Jalilvand, Hank, & Mosich, 2015), basketball (Chaouachi et al., 2009) and handball (Iacono et al., 2017). Although COD capabilities are task-specific, COD ability is distinct from agility (Holmberg, 2009; Young, Miller, & Talpey, 2015). The factor that distinguishes COD ability and agility is the unchanging environment the COD manoeuvre occurs in (Holmberg, 2009). Despite largely excluding cognitive processes such as decision making and perception-action coupling, COD tasks are a common feature in team-sport testing batteries due to the practical regard for these capabilities.

Athletic manoeuvres can provide objective measures that assist in talent identification and selection (Hart, Spiteri, Lockie, Nimphius, & Newton, 2014; Robbins, 2010; Sierer et al., 2008), and can be used to monitor changes in task-specific performance (Nimphius et al., 2010; Thomas, Mather, & Comfort, 2014) (Chapter 2 and Chapter 3). Chapter 3 established the reliability and predictive power of individualised MDJ tasks that aim to replicate the rapid unilateral stretch-shortening actions that are generally associated with COD tasks.

It was suggested in Chapter 2 that practitioners consider a velocity-based continuum when describing and explaining COD capabilities (Figure 2.1). In addition to providing more accurate description and explanation, this continuum that is based on the magnitudes of speed *and* direction gives insight into potentially important neuromuscular factors that should be trained to improve performance. Identifying factors that discriminate performances in COD tasks associated with field sports would be beneficial for strength and conditioning practitioners. Previous reports have identified the 180-degree and 45-degree COD manoeuvres to be positively associated with the on-the-field attributes such as tackling (Gabbett, 2009) and sidestepping (Green et al., 2011; Spiteri et al., 2013), respectively. Understanding the characteristics underpinning faster 180-degree and 45-degree COD performances would increase the likelihood of a positive performance outcome, and increase the validity of measures used in monitoring and talent identification. This information would potentially provide parameters that guide practitioners in the selection of appropriate COD drills. Additionally, understanding the characteristics of COD manoeuvres would also assist in

establishing the structure and timing of the COD training plan. For instance, many COD manoeuvres executed in competition require rapid direction changes in an environment with high contextual interference (Bain & McGown, 2010; Holmberg, 2009). With this in mind, the strength and conditioning professional may prepare the athlete by briefly introducing COD manoeuvres in a less challenging environment (i.e. low contextual interference) and progress to executing the COD manoeuvres in a sport-specific environment (Bain & McGown, 2010; Enoka, 2008; Holmberg, 2009; Schmidt & Lee, 2013).

In addition to training the criterion COD task(s) to enhance performance, practitioners may also use other training modes (e.g. jumping) that share more similar neuromuscular requirements with the criterion COD task(s). Multidirectional jump performance has been suggested to be associated with performance in COD tasks (Green et al., 2011) (Chapter 3). Chapter 3 revealed moderate to large correlation (r = -0.71 to -0.45) between MDJ distance and total time to complete 180-degree and 45-degree COD tasks. Chapter 3 also showed MDJ distance was successful in predicting total time to complete 180-degree and 45-degree COD tasks. Understanding underlying factors of the MDJ and COD tasks would assist in exercise selection, scheduling and timing potentially increasing the likelihood of a positive training outcome.

Therefore, the purpose of this study was to 1) examine plant-step kinetics that distinguish faster and slower performances in 180-degree and 45-degree COD tasks; and 2) determine associations between COD and MDJ performance variables. It was hypothesised faster performances would be associated with better COD and MDJ plant-step kinetics; and task-specific association between COD and MDJ performance variables exists.

Methods

Experimental approach to the problem

A cross-sectional design was used to examine MDJ and COD plant-step kinetics, and quantify relationships between MDJ and COD performance. The reliability of the tests were determined by having participants perform the COD (ICC = 0.918 to 0.960, CV = 1.5 to 2.3%) and MDJ (ICC = 0.969 to 0.980, CV = 3.0 to 4.3%) tasks at two time periods separated by seven days. Prior to testing, participants completed two one-hour familiarisation sessions separated by 24 hours. It should be noted that each

familiarisation and testing session was performed during the same time of day to control diurnal effects (Teo et al., 2011).

Subjects

Nineteen males (age: 27.6 ± 6.0 yr; body mass: 79.7 ± 12.7 kg; height: 1.8 ± 0.1 m; leg length: 0.85 ± 0.1 m) volunteered. The cohort consisted of team-sport (n = 14) and individual-sport (n = 5) athletes. Participants were from a wide array of sports which consisted of rugby union, rugby league, American football, football, basketball, cricket, athletics and weightlifting. The criteria for training status was a minimum of one hour of structured resistance and conditioning training at least three days per week (Baechle & Earle, 2008). All volunteers were also required to have a minimum of one year of systematic resistance training. Each participant had the benefits and risks of the investigation explained to them verbally and in written form, and signed an informed consent before participation. The Auckland University of Technology Ethics Committee approved all procedures undertaken in this study (15/322).

Procedures

All participants were instructed to refrain from unaccustomed or vigorous activity (e.g. 1-RM testing) 48 hours prior to testing; however, volunteers continued usual training and activities. This was done to control sudden changes in physical activity which can influence performance and reliability. First, anthropometry (height, weight and right-leg length) were measured. Second, assessment and plant-leg order were randomised and counterbalanced. That is, the sequence of tests and the leg to ultimately serve as the 'COD limb' were selected and ordered by blinded drawing. This method was used to control order effects. Next, two familiarisation sessions, separated by 24-hours, were conducted which included a standardised warm-up and identical tests described below, in the same order. The warm-up consisted of five minutes of submaximal jogging followed by five minutes of multi-joint dynamic stretches. Twenty-four hours after the second familiarisation experimental testing began using identical protocols. While participants were instructed to perform all familiarisation and testing tasks with maximum effort, neither verbal encouragement nor technical cueing were given as this may influence results (Khuu et al., 2015). Also, all participants wore similar athletic clothing (e.g. t-shirt and shorts) and the same athletic shoes for all familiarisation and testing sessions.

Anthropometrics

Body height was measured using a stadiometer (Holtain limited, Harpenden, Wales, UK) and leg length was measured on the right leg from the greater trochanter to the lateral malleolus with a measuring tape and used to calculate 1.5 and 2.5 times leg lengths (Mirwald et al., 2002). All leg lengths were rounded to the nearest centimetre. Next, body weight was measured using an embedded force plate (Type: 9287BA, Kistler Instrumente AG, Switzerland).

Change of direction assessment

Change of direction performance in left- and right-plant leg tasks that require large and more modest direction changes were assessed using a 180-degree and a 45-degree manoeuvre, respectively (Figure 3.1). To eliminate the influence of reaction time on total sprint time participants began each trial at their own volition. Five attempts per assessment were given for both left- and right-plant legs with approximately two min rest between each trial. The contact zone for all attempts was marked with tape to increase consistency in foot placement during the plant-step. Both COD contact zones were selected due to the average touchdown position of the plant foot during pilot testing. Successful trial criteria were: maximum effort throughout the test; sprinting within the designated 1.20 m path; foot contact within the designated contact zone; and effort given to total trial time rather than plant-step placement.

A modified 505 was used to measure 180-degree COD performance (Sasaki et al., 2011). This assessment was selected based upon previous investigations demonstrating value in this COD task in relation to contact team sports (Gabbett, 2009). Most importantly, this test served as the COD manoeuvre that required a larger magnitude of direction change (i.e. 180-degree angle change). Participants began 0.30 m behind the start line in a staggered stance with the non-plant limb as the lead leg. Next, participants sprinted forwards, then executed a 180-degree turn in the 0.15 m × 0.60 m contact zone, before sprinting back in the opposite direction through the start/finish line.

The second COD assessment was a 45-degree cutting task. This test also served as a COD measure that is more specific to attacking manoeuvres in team sports (Green et al., 2011). Most importantly, this test served as the COD task that required a more modest direction change (i.e. 45-degree angle change). As with the 180-degree task the participant began in a staggered stance. When ready participants sprinted forwards,

executed a 45-degree direction change (placing the respective foot within the 0.30 m × 0.60 m contact zone), then sprinted through the finish gate. A goniometer and tape were used to mark the sprint path after the plant-step.

A high-speed digital camera (Casio, Exilim EX-FH20, Tokyo, Japan) and timing lights (Speed Light V2 gate, Swift, Wacol, QLD, Australia) were used to monitor trial quality and measure sprint times of each assessment, respectively. Plant-step kinetics were collected at 1000 Hz with an embedded force plate (Type: 9287BA, Kistler Instrumente AG, Switzerland) using DAQ system with BioWare 4.0 software (Type: 5691A1, Kistler Instrumente AG, Switzerland). Plant-step kinetics were collected during the interval between initial contact and toe-off with threshold readings of 50 N. Variables of interest were total COD sprint time, ground contact time, mean force, RFD and percent contribution of x- (medial-lateral), y- (anterior-posterior) and z-axis (vertical) force to net force and net impulse.

Multidirectional jump assessment

The MDJ task was a modification of previously reported protocols (Inaba et al., 2013; Ruan & Li, 2008; Serpell et al., 2014) (Figure 3.2). Participants began in a bilateral stance facing the single-leg landing point located in a 0.30 m × 0.60 m contact area.

When ready participants executed a bilateral horizontal jump, made ground contact with a single leg, immediately jumped 45-degree to the contralateral side, then landed on two feet while simultaneously facing the new direction. Distances of the approach jump towards the contact area were equal to 1, 1.5 and 2.5 × leg-length with tape marking the respective start point. Leg length was used to individualise the jump task due to previous demonstrations of mechanical output being influenced by preliminary movement (Ruan & Li, 2008). Participants were required to demonstrate postural control throughout the attempt, and land on both feet. If the aforementioned were not satisfied, another attempt was given. No preparatory step in the first bilateral jump was allowed, however, no restrictions were placed on the swing of the arms or the contralateral leg. Participants were given five attempts on each leg at each leg length with one min rest between each attempt. A high-speed digital camera (Casio, Exilim EX-FH20, Tokyo, Japan) was used assess the quality and distance of each jump. The camera was placed 4.5 m perpendicular to a 45-degree line that extended 3 m from the centre of the contact area. Distance of the unilateral jump (i.e. the second jump) was calculated by importing the video captured at 120 frames·s^{-1} into kinematic analysis

software (Kinovea, version 0.8.15). The toe at first touchdown and heel at second touchdown of the jump leg served as the measurement points. The software was calibrated using a 1 m marking that was parallel to the 45-degree single-leg jump path. Plant-step kinetics were collected and analysed in the same manner as the COD tests. Variables of interest were unilateral jump distance, ground contact time, mean force and impulse, RFD, and percent contribution of x-, y- and z-axis force to net force and net impulse.

Statistical analysis

Using previously reported data (Oliver & Meyers, 2009), sample size estimation was calculated *a priori* using commercially available software (G*Power, version 3.0.10). The reliability coefficient and effect size were set to 0.75 and 0.4, respectively, and yielded a sample size estimation of 18 total participants.

The central tendency and dispersion of the data were calculated for all variables as mean ± SD. The mean scores of each measurement were used for analysis. All data were log transformed to reduce non-uniformity of error (Hopkins et al., 2009; Hopkins, 2000). Group median, calculated from the between-individual mean scores of left- and right-leg 180-degree and 45-degree COD tests, were used to separate faster (FAST) and slower (SLOW) individuals for categorical comparison. The between-individual SD was used to calculate the coefficient of variation (CV) relative to the mean. Additionally, Cohen's *d* ES was used to quantify categorical differences. Thresholds of 0.2, 0.6, 1.2 and >2.0 were used for ES magnitudes of small, moderate, large and very large, respectively (Hopkins et al., 2009). Pearson's correlation coefficient (r) and coefficient of determination (r^2) were used to quantify association and shared variance among performance variables, respectively. Pearson's r thresholds of nearly perfect, very large, large, moderate, small and trivial were 0.9, 0.7, 0.5, 0.3, 0.1 and <0.1, respectively (Hopkins, 2000).

Results

Change of direction performance

Total trial time

For the 180-degree COD task, FAST was 6.2% and 7.3% faster than SLOW in left and right plant-limb tests, respectively (Table 4.1). Regarding the 45-degree COD task

FAST was 8.8% and 10.0% faster than SLOW in the left and right-plant-limb tests, respectively (Table 4.2). Within-group comparison revealed there was trivial asymmetry between left and right plant-limb 180-degree and 45-degree COD performances.

Table 4.1. Between-group comparison of left and right plant-limb 180-degree change of direction tasks.

	180-degree COD task			
	Left plant-limb		Right plant-limb	
	Fast group (n = 10)	Slow group (n = 9)	Fast group (n = 10)	Slow group (n = 9)
Mean trial time (s)	2.64 ± 0.06	2.81 ± 0.07	2.63 ± 0.07	2.83 ± 0.07
CV(%)	2.18	2.50	2.51	2.60
Effect size	1.59		1.63	
Magnitude	Large		Large	
Median trial time (s)	2.71		2.70	

Table 4.2. Between-group comparison of left and right plant-limb 45-degree change of direction tasks.

	45-degree COD task			
	Left plant-limb		Right plant-limb	
	Fast group (n = 10)	Slow group (n = 9)	Fast group (n = 10)	Slow group (n = 9)
Mean trial time (s)	1.62 ± 0.04	1.77 ± 0.06	1.61 ± 0.06	1.78 ± 0.09
CV (%)	2.19	3.37	4.02	5.09
Effect size	1.67		1.45	
Magnitude	Large		Large	
Median trial time (s)	1.66		1.70	

Plant-step kinetics

For the LT180 COD, FAST had shorter GCT (13.3%), greater mean and relative mean Fy (21.0% and 23.3%, respectively), and greater mean and relative mean Fz (25.6% and 28.6%, respectively) when compared to SLOW. Similarly, the RT180 FAST showed greater mean and relative mean Fy (20.1% and 23.3%, respectively) and relative mean Fz (24.4%) (Table 4.3).

For the LT45 COD, FAST presented shorter GCT (11.1%) and slower RFD for Fx and Fz (24.4% and 34.8%, respectively). For the RT45 COD, FAST showed greater mean and relative mean Fx (15.4% and 17.0%, respectively), greater mean and relative mean Fz (26.5% and 23.0%, respectively), and greater RFD for Fx (29.9%, respectively) (Table 4.4).

Table 4.3. Between-group comparison of kinetic variables in left and right plant-limb 180-degree change of direction tasks.

	Left 180-degree change of direction task				Right 180-degree change of direction task			
Variable	Fast (*n*=10)	Slow (*n*=9)	ES		Fast (*n*=10)	Slow (*n*=9)	ES	
Ground contact time (s)	0.42 ± 0.08	0.48 ± 0.11	0.67	M	0.54 ± 0.34	0.52 ± 0.06	-0.12	T
Max Fx (N)	271.28 ± 75.58	259.09 ± 86.16	-0.16	T	263.79 ± 54.89	257.84 ± 52.65	-0.11	T
Max Rel Fx ($N \cdot N^{-1}$)†	0.35 ± 0.10	0.33 ± 0.09	-0.21	S	0.34 ± 0.07	0.33 ± 0.04	-0.26	S
Max Fy (N)	1191.96 ± 260.62	1057.29 ± 356.16	-0.44	S	1146.6 ± 296.24	1036.77 ± 344.44	-0.35	S
Max Rel Fy ($N \cdot N^{-1}$)†	1.53 ± 0.24	1.34 ± 0.41	-0.58	S	1.47 ± 0.23	1.30 ± 0.35	-0.55	S
Max Fz (N)	1403.16 ± 249.86	1322.85 ± 296.60	-0.30	S	1448.73 ± 323.17	1319.13 ± 387.05	-0.37	S
Max Rel Fz ($N \cdot N^{-1}$)†	1.81 ± 0.22	1.70 ± 0.36	-0.39	S	1.85 ± 0.26	1.67 ± 0.35	-0.58	S
Mean Fx (N)	24.41 ± 40.14	28.07 ± 44.08	-0.09	T	137.33 ± 480.22	21.10 ± 23.14	0.45	S
Mean Rel Fx ($N \cdot N^{-1}$)†	0.03 ± 0.06	0.04 ± 0.05	-0.06	T	0.17 ± 0.59	0.02 ± 0.03	0.45	S
Mean Fy (N)	749.27 ± 137.70	606.64 ± 223.75	-0.74	M	745.95 ± 130.11	609.42 ± 222.94	-0.73	M
Mean Rel Fy ($N \cdot N^{-1}$)†	0.96 ± 0.08	0.76 ± 0.23	-1.06	M	0.96 ± 0.08	0.76 ± 0.24	-1.01	M
Mean Fz (N)	876.40 ± 159.98	677.84 ± 416.94	0.63	M	890.65 ± 141.78	725.30 ± 415.46	0.54	S

Mean Rel Fz ($N \cdot N^{-1}$)†	1.12 ± 0.07	0.84 ± 0.55	0.73	M	1.15 ± 0.03	0.90 ± 0.53	0.66	M
RFD Fx	75.40 ± 42.26	65.89 ± 30.63	-0.26	S	73.95 ± 25.09	76.37 ± 21.84	0.11	T
RFD Fy	76.59 ± 25.99	74.01 ± 26.66	-0.10	T	76.83 ± 25.59	74.81 ± 21.29	-0.09	T
RFD Fz	147.73 ± 91.24	129.09 ± 62.98	-0.24	S	144.47 ± 55.43	131.93 ± 49.96	-0.24	S
Rel contribution Fx	0.34 ± 0.93	0.11 ± 0.30	-0.33	S	0.31 ± 0.75	0.002 ± 0.21	0.53	S
Rel contribution Fy	6.39 ± 7.44	3.74 ± 2.10	0.47	S	14.00 ± 30.08	2.74 ± 1.38	0.51	S
Rel contribution Fz	7.04 ± 6.55	4.68 ± 2.00	-0.48	S	15.31 ± 30.82	3.75 ± 1.55	-0.51	S

† = relative to body weight (N); Fx = medial-lateral force, Fy = anterior-posterior force, Fz = vertical force; RFD = rate of force development, Rel contribution = relative contribution; ES = effect size, T = trivial ES, S = small ES, M = moderate ES, L = large ES.

Table 4.4. Between-group comparison of kinetic variables in left and right plant-limb 45-degree change of direction tasks.

	Left 45-degree change of direction task				Right 45-degree change of direction task			
Variable	Fast (*n*=10)	Slow (*n*=9)	ES		Fast (*n*=10)	Slow (*n*=9)	ES	
Ground contact time (s)	0.17 ± 0.02	0.19 ± 0.02	0.91	M	0.17 ± 0.02	0.18 ± 0.02	0.37	S
Max Fx (N)	1174.81 ± 222.52	1317.83 ± 320.72	0.52	S	1303.3 ± 352.28	1065.83 ± 282.76	-0.71	M
Max Rel Fx ($N \cdot N^{-1}$)†	1.55 ± 0.28	1.64 ± 0.27	0.31	S	1.67 ± 0.35	1.35 ± 0.20	-0.99	M
Max Fy (N)	844.77 ± 250.34	1086.96 ± 365.33	0.74	M	1031.67 ± 353.61	791.73 ± 299.51	-0.70	M
Max Rel Fy ($N \cdot N^{-1}$)†	1.12 ± 0.36	1.35 ± 0.40	0.60	S	1.34 ± 0.49	1.01 ± 0.34	-0.74	M
Max Fz (N)	2090.35 ± 403.02	2386.87 ± 717.61	0.51	S	2429.01 ± 839.96	1999.67 ± 679.21	-0.55	S
Max Rel Fz ($N \cdot N^{-1}$)†	2.75 ± 0.42	2.96 ± 0.72	0.35	S	3.10 ± 0.96	2.52 ± 0.70	-0.66	M
Mean Fx (N)	722.36 ± 130.72	745.81 ± 170.11	-0.16	T	793.52 ± 181.42	679.84 ± 171.43	0.63	M
Mean Rel Fx ($N \cdot N^{-1}$)†	0.96 ± 0.15	0.92 ± 0.07	0.30	S	1.02 ± 0.15	0.86 ± 0.10	1.07	M
Mean Fy (N)	224.68 ± 133.53	257.58 ± 281.07	0.16	T	243.76 ± 164.82	324.53 ± 305.94	-0.34	S
Mean Rel Fy ($N \cdot N^{-1}$)†	0.30 ± 0.20	0.31 ± 0.40	0.01	T	0.32 ± 0.25	0.41 ± 0.37	-0.29	S
Mean Fz (N)	1124.87 ± 495.97	1054.41 ± 498.59	0.15	T	1219.64 ± 408.24	934.55 ± 434.40	0.66	M
Mean Rel Fz ($N \cdot N^{-1}$)†	1.45 ± 0.58	1.30 ± 0.62	0.25	S	1.55 ± 0.43	1.23 ± 0.57	0.63	M

RFD Fx	165.45 ± 57.45	211.46 ± 55.84	0.77	M	258.48 ± 120.49	191.18 ± 83.57	-0.63	M
RFD Fy	277.56 ± 174.93	259.84 ± 132.46	-0.12	T	322.08 ± 126.75	256.14 ± 127.59	-0.51	S
RFD Fz	267.77 ± 114.57	380.57 ± 122.15	0.88	M	366.13 ± 159.32	331.60 ± 181.63	-0.21	S
Rel contribution Fx	0.39 ± 0.07	0.40 ± 0.03	0.14	T	0.32 ± 0.03	0.31 ± 0.03	-0.33	S
Rel contribution Fy	0.10 ± 0.05	0.16 ± 0.03	-1.11	M	0.11 ± 0.08	0.08 ± 0.02	-0.36	S
Rel contribution Fz	0.71 ± 0.04	0.72 ± 0.10	0.10	T	0.56 ± 0.15	0.61 ± 0.03	0.42	S

† = relative to body weight (N); Fx = medial-lateral force, Fy = anterior-posterior force, Fz = vertical force; RFD = rate of force development, Rel contribution = relative contribution; ES = effect size, T = trivial ES, S = small ES, M = moderate ES, L = large ES.

Multidirectional jump performance

Jump distance

For the left-leg MDJ, the LT45 COD faster group produced greater absolute and relative jump distances for MDJ 1 × leg-length (19.9%, ES = -1.21 and 16.9%, ES = 1.18, respectively), 1.5 × leg-length (21.5%, ES = -1.25 and 18.6%, ES = -1.24, respectively) and 2.5 × leg-length (18.4%, ES = -1.12 and 18.2%, ES = -1.11, respectively) (Table 4.5). For right-leg MDJ, the RT45 COD faster group produced a greater absolute and relative distance for MDJ 1 × leg-length (24.9%, ES = -1.40 and 22.5%, ES = -1.35, respectively), 1.5 × leg-length (24.0%, ES = -1.41 and 21.6%, ES = -1.36, respectively), and 2.5 × leg-length (22.0%, ES = -1.34 and 19.5%, ES = -1.26, respectively) (Table 4.6).

Plant-step kinetics

For the left-leg MDJ, the LT45 COD faster group produced greater GCT:distance ratios for MDJ 1 × leg-length (13.3%, ES = 0.86), MDJ 1.5 × leg-length (28.6%, ES = 1.07) and MDJ 2.5 × leg-length (15.4%, ES = 0.61). Five y-axis force variables and three z-axis force variables distinguished faster and slower individuals in the LT45 (Table 4.5). For right-leg MDJ, the RT45 COD faster group similarly produced greater GCT:distance ratios for MDJ 1 × leg-length (30.3%, ES = 1.14), MDJ 1.5 × leg-length (26.7%, ES = 1.06) and MDJ 2.5 × leg-length (19.5%, ES = 0.89). Individuals in the RT45 faster group displayed three x-axis, two y-axis and three z-axis force variables to be distinguishing factors in right-oriented MDJ performance (Table 4.6).

Table 4.5. Comparison of left plant-leg multidirectional jump variables of faster and slower individuals in the left-leg 45-degree change of direction task.

	Left-plant limb											
	MDJ 1 × leg-length				MDJ 1.5 × leg-length				MDJ 2.5 × leg-length			
Variable	Fast (*n*=10)	Slow (*n*=9)	ES		Fast (*n*=10)	Slow (*n*=9)	ES		Fast (*n*=10)	Slow (*n*=9)	ES	
Distance (m)	2.21 ± 0.25	1.81 ± 0.28	-1.21	L	2.32 ± 0.28	1.87 ± 0.28	-1.25	L	2.37 ± 0.33	1.97 ± 0.25	-1.12	M
Rel distance ($m \cdot m^{-1}$)‡	2.57 ± 0.30	2.17 ± 0.25	-1.18	M	2.70 ± 0.34	2.24 ± 0.25	-1.24	L	1.32 ± 0.20	1.10 ± 0.11	-1.11	M
GCT (s)	0.34 ± 0.04	0.35 ± 0.04	0.14	T	0.33 ± 0.03	0.35 ± 0.06	0.54	S	0.33 ± 0.05	0.32 ± 0.03	-0.32	S
GCT:distance ($s \cdot m^{-1}$)	0.14 ± 0.03	0.16 ± 0.03	0.86	M	0.12 ± 0.02	0.16 ± 0.03	1.07	M	0.12 ± 0.02	0.14 ± 0.02	0.61	M
Max Fx (N)	663.14 ± 116.54	634.15 ± 138.65	-0.23	S	706.15 ± 138.24	652.68 ± 149.99	-0.38	S	842.56 ± 264.76	819.28 ± 184.10	-0.11	T
Max Rel Fx ($N \cdot N^{-1}$)†	0.87 ± 0.09	0.79 ± 0.13	-0.71	M	0.91 ± 0.09	0.83 ± 0.13	-0.68	M	1.08 ± 0.24	1.04 ± 0.15	-0.17	T
Max Fy (N)	395.18 ± 83.88	379.75 ± 134.87	-0.14	T	437.77 ± 138.02	420.65 ± 185.57	-0.11	T	903.38 ± 361.55	831.96 ± 316.00	-0.21	S
Max Rel Fy ($N \cdot N^{-1}$)†	0.52 ± 0.10	0.47 ± 0.13	-0.49	S	0.56 ± 0.13	0.52 ± 0.17	-0.26	S	1.14 ± 0.33	1.05 ± 0.32	-0.30	S
Max Fz (N)	2277.18 ± 1254.81	1922.61 ± 626.80	-0.36	S	2337.57 ± 994.37	2135.71 ± 825.37	-0.22	S	3192.09 ± 1210.07	2881.14 ± 1327.00	-0.25	S
Max Rel Fz ($N \cdot N^{-1}$)†	2.92 ± 1.25	2.36 ± 0.64	-0.55	S	2.95 ± 0.99	2.68 ± 0.86	-0.29	S	4.04 ± 1.20	3.66 ± 1.47	-0.29	S

LT = left plant-leg, RT = right plant-leg, 1 = 1 × leg length, 1.5 = 1.5 × leg length, 2.5 = 2.5 × leg length † = relative to body weight (N); Fx = medial-lateral force, Fy = anterior-posterior force, Fz = vertical force; ES = effect size, T = trivial ES, S = small ES, M = moderate ES, L = large ES.

Table 4.5 (cont.). Comparison of left plant-leg multidirectional jump variables of faster and slower individuals in the left-leg 45-degree change of direction task.

	Left-plant limb											
	MDJ 1 × leg-length				MDJ 1.5 × leg-length				MDJ 2.5 × leg-length			
Variable	Fast (*n*=10)	Slow (*n*=9)	ES		Fast (*n*=10)	Slow (*n*=9)	ES		Fast (*n*=10)	Slow (*n*=9)	ES	
Mean Fx (N)	282.65 ± 125.69	346.05 ± 145.40	-0.47	S	478.51 ± 108.82	448.94 ± 98.84	0.29	S	503.89 ± 100.16	469.87 ± 88.49	0.36	S
Mean Rel Fx ($N \cdot N^{-1}$)†	0.37 ± 0.16	0.42 ± 0.15	-0.33	S	0.61 ± 0.10	0.57 ± 0.09	0.43	S	0.65 ± 0.08	0.60 ± 0.08	0.57	S
Mean Fy (N)	552.06 ± 483.18	412.22 ± 548.47	0.28	S	98.41 ± 103.71	18.33 ± 63.79	0.85	M	57.52 ± 141.55	57.78 ± 112.31	0.00	T
Mean Rel Fy ($N \cdot N^{-1}$)†	0.76 ± 0.67	0.53 ± 0.71	0.33	S	0.14 ± 0.15	0.03 ± 0.09	0.77	M	0.06 ± 0.20	0.07 ± 0.16	0.02	T
Mean Fz (N)	1321.90 ± 307.85	1341.18 ± 256.06	-0.07	T	1238.21 ± 564.50	1094.91 ± 541.67	0.26	S	1391.13 ± 495.60	987.72 ± 547.78	0.74	M
Mean Rel Fz ($N \cdot N^{-1}$)†	1.73 ± 0.19	1.67 ± 0.20	0.24	S	1.54 ± 0.59	1.42 ± 0.70	0.18	T	1.76 ± 0.55	1.28 ± 0.74	0.72	M

LT = left plant-leg, RT = right plant-leg, 1 = 1 × leg length, 1.5 = 1.5 × leg length, 2.5 = 2.5 × leg length † = relative to body weight (N); Fx = medial-lateral force, Fy = anterior-posterior force, Fz = vertical force; ES = effect size, T = trivial ES, S = small ES, M = moderate ES, L = large ES.

Table 4.5 (cont.). Comparison of left plant-leg multidirectional jump variables of faster and slower individuals in the left-leg 45-degree change of direction task.

	Left-plant limb											
	MDJ 1 × leg-length				MDJ 1.5 × leg-length				MDJ 2.5 × leg-length			
Variable	Fast (*n*=10)	Slow (*n*=9)	ES		Fast (*n*=10)	Slow (*n*=9)	ES		Fast (*n*=10)	Slow (*n*=9)	ES	
RFD Fx	78.86 ± 32.04	95.03 ± 36.26	0.47	S	118.92 ± 54.63	114.04 ± 24.38	-0.12	T	192.30 ± 86.73	154.48 ± 59.25	-0.50	S
RFD Fy	108.48 ± 60.35	143.02 ± 62.62	0.55	S	200.52 ± 142.36	155.47 ± 73.45	-0.39	S	271.37 ± 144.29	232.59 ± 110.32	-0.30	S
RFD Fz	226.24 ± 115.31	241.16 ± 114.17	0.13	T	262.41 ± 139.52	320.66 ± 130.70	0.43	S	479.78 ± 174.51	412.68 ± 244.82	-0.32	S
Rel contribution Fx	0.24 ± 0.03	0.23 ± 0.02	-0.20	S	0.25 ± 0.03	0.24 ± 0.03	-0.23	S	0.26 ± 0.02	0.26 ± 0.06	0.08	T
Rel contribution Fy	0.08 ± 0.07	0.03 ± 0.03	-0.92	M	0.03 ± 0.03	0.01 ± 0.03	-1.12	M	0.04 ± 0.03	0.05 ± 0.02	-0.35	S
Rel contribution Fz	0.66 ± 0.17	0.74 ± 0.04	0.64	M	0.72 ± 0.04	0.77 ± 0.05	0.86	M	0.78 ± 0.03	0.77 ± 0.08	-0.20	S

‡ = relative to leg length, † = relative to body weight (N); Fx = medial-lateral force, Fy = anterior-posterior force, Fz = vertical force; RFD = rate of force development, Rel contribution

= relative contribution; ES = effect size, T = trivial ES, S = small ES, M = moderate ES, L = large ES.

Table 4.6. Comparison of right plant-leg multidirectional jump variables of faster and slower individuals in the right-leg 45-degree change of direction task.

	Right-plant limb											
	MDJ 1 × leg-length				MDJ 1.5 × leg-length				MDJ 2.5 × leg-length			
Variable	Fast (*n*=10)	Slow (*n*=9)	ES		Fast (*n*=10)	Slow (*n*=9)	ES		Fast (*n*=10)	Slow (*n*=9)	ES	
Distance (m)	2.12 ± 0.25	1.65 ± 0.24	-1.40	L	2.19 ± 0.23	1.72 ± 0.25	-1.41	L	2.27 ± 0.26	1.82 ± 0.24	-1.34	L
Rel distance ($m \cdot m^{-1}$)‡	2.47 ± 0.33	1.97 ± 0.21	-1.35	L	2.56 ± 0.31	2.06 ± 0.23	-1.36	L	2.65 ± 0.34	2.18 ± 0.23	-1.26	L
GCT (s)	0.34 ± 0.04	0.37 ± 0.09	0.47	S	0.33 ± 0.04	0.34 ± 0.04	0.26	S	0.33 ± 0.04	0.33 ± 0.05	0.05	T
GCT:distance ($s \cdot m^{-1}$)	0.14 ± 0.03	0.19 ± 0.04	1.14	M	0.13 ± 0.03	0.17 ± 0.03	1.06	M	0.13 ± 0.03	0.15 ± 0.03	0.89	M
Max Fx (N)	658.59 ± 134.07	616.86 ± 134.74	-0.32	S	701.79 ± 114.72	684.45 ± 174.85	-0.12	T	829.94 ± 197.78	815.57 ± 280.73	-0.06	T
Max Rel Fx ($N \cdot N^{-1}$)†	0.86 ± 0.12	0.77 ± 0.13	-0.73	M	0.93 ± 0.12	0.85 ± 0.17	-0.53	S	1.10 ± 0.24	1.01 ± 0.29	-0.32	S
Max Fy (N)	412.29 ± 101.24	383.31 ± 124.59	-0.26	S	444.23 ± 182.85	434.80 ± 92.99	-0.07	T	740.26 ± 273.11	996.36 ± 299.99	0.83	M
Max Rel Fy ($N \cdot N^{-1}$)†	0.54 ± 0.09	0.47 ± 0.12	-0.60	S	0.58 ± 0.18	0.54 ± 0.11	-0.21	S	0.96 ± 0.25	1.23 ± 0.28	0.93	M
Max Fz (N)	2091.00 ± 947.13	2093 ± 826.03	0.00	T	2222.32 ± 1058.50	2415.95 ± 912.43	0.20	S	3133.9 ± 3382.1	3382.1 ± 1507.7	0.18	T
Max Rel Fz ($N \cdot N^{-1}$)†	2.68 ± 0.88	2.57 ± 0.86	-0.14	T	2.84 ± 1.01	2.97 ± 0.94	0.14	T	4.03 ± 1.23	4.11 ± 1.44	0.06	T

‡ = relative to leg length, † = relative to body weight (N); Fx = medial-lateral force, Fy = anterior-posterior force, Fz = vertical force; RFD = rate of force development, Rel contribution = relative contribution;

ES = effect size, T = trivial ES, S = small ES, M = moderate ES, L = large ES.

Table 4.6 (cont.). Comparison of right plant-leg multidirectional jump variables of faster and slower individuals in the right-leg 45-degree change of direction task.

	Right-plant limb											
	MDJ 1 × leg-length				MDJ 1.5 × leg-length				MDJ 2.5 × leg-length			
Variable	Fast (*n*=10)	Slow (*n*=9)	ES		Fast (*n*=10)	Slow (*n*=9)	ES		Fast (*n*=10)	Slow (*n*=9)	ES	
Mean Fx (N)	467.23 ± 89.34	411.43 ± 117.46	0.53	S	277.63 ± 630.21	475.28 ± 113.46	-0.43	S	502.8 ± 83.06	458.9 ± 93.81	0.5	S
Mean Rel Fx ($N \cdot N^{-1}$)†	0.62 ± 0.09	0.51 ± 0.09	1.03	M	0.42 ± 0.72	0.59 ± 0.11	-0.33	S	0.67 ± 0.10	0.58 ± 0.14	-0.21	S
Mean Fy (N)	109.62 ± 147.59	57.31 ± 123.57	-0.39	S	45.67 ± 131.62	20.31 ± 117.13	-0.52	S	106.7 ± 120.69	135.3 ± 73.43	-0.29	S
Mean Rel Fy ($N \cdot N^{-1}$)†	0.14 ± 0.21	0.06 ± 0.17	-0.40	S	0.05 ± 0.19	0.04 ± 0.16	-0.53	S	0.14 ± 0.18	0.18 ± 0.11	-0.21	S
Mean Fz (N)	1211.31 ± 475.04	1149.92 ± 454.08	0.14	T	1290.38 ± 468.26	1283.25 ± 424.99	0.02	T	1238.88 ± 531.31	1384.62 ± 428.13	-0.31	S
Mean Rel Fz ($N \cdot kg^{-1}$)†	1.58 ± 0.56	1.41 ± 0.52	0.30	T	1.67 ± 0.53	1.58 ± 0.46	0.19	T	1.60 ± 0.60	1.71 ± 0.46	-0.20	T

‡ = relative to leg length, † = relative to body weight (N); Fx = medial-lateral force, Fy = anterior-posterior force, Fz = vertical force; RFD = rate of force development, Rel contribution = relative contribution; ES = effect size, T = trivial ES, S = small ES, M = moderate ES, L = large ES.

Table 4.6 (cont.). Comparison of right plant-leg multidirectional jump variables of faster and slower individuals in the right-leg 45-degree change of direction task.

	Right-plant limb											
	MDJ 1 × leg-length				MDJ 1.5 × leg-length				MDJ 2.5 × leg-length			
Variable	Fast (*n*=10)	Slow (*n*=9)	ES		Fast (*n*=10)	Slow (*n*=9)	ES		Fast (*n*=10)	Slow (*n*=9)	ES	
RFD Fx	81.50 ± 23.46	101.06 ± 55.34	0.47	S	90.45 ± 62.59	122.50 ± 37.58	0.60	S	196.1 ± 78.77	162.15 ± 54.33	-0.49	S
RFD Fy	119.89 ± 61.77	110.74 ± 50.21	-0.17		153.92 ± 123.62	142.44 ± 63.57	-0.12	T	235.6 ± 115.49	328.38 ± 146.41	0.68	M
RFD Fz	192.60 ± 80.64	272.96 ± 139.23	0.69	M	205.58 ± 159.67	334.10 ± 147.78	0.79	M	408.12 ± 143.49	459.26 ± 228.22	0.28	S
Rel contribution F	0.26 ± 0.03	0.24 ± 0.04	-0.63	M	0.27 ± 0.04	0.24 ± 0.03	0.39	S	0.24 ± 0.04	0.23 ± 0.02	-0.48	S
Rel contribution Fy	0.05 ± 0.09	0.02 ± 0.08	0.37	S	-0.02 ± 0.04	0.004 ± 0.04	0.60	S	0.06 ± 0.07	0.05 ± 0.03	-0.11	T
Rel contribution Fz	0.74 ± 0.22	0.73 ± 0.21	-0.07	T	0.61 ± 0.49	0.75 ± 0.02	0.79	M	0.72 ± 0.04	0.72 ± 0.03	-0.14	T

‡ = relative to leg length, † = relative to body weight (N); Fx = medial-lateral force, Fy = anterior-posterior force, Fz = vertical force; RFD = rate of force development, Rel contribution = relative contribution; ES = effect size, T = trivial ES, S = small ES, M = moderate ES, L = large ES.

Interclass correlation

Group trial time for faster 180-degree COD performances possessed large correlation with four MDJ distances (r = -0.664 to -0.743) and six 180-degree COD plant-step variables (r = -0.728 to 0.680). Shared variance (r^2) faster 180-degree COD trial times had with MDJ distance and COD plant-step variables ranged from 44.1 to 55.2% and 42.9 to 53.4%, respectively. Faster 45-degree COD group trial time possessed a large correlation with two MDJ distances (r = -0.716 and -0.720, p = 0.02) and two MDJ plant-step variables (r = 0.649 and 0.735, p = 0.02 and 0.04, respectively). Faster left- and right-leg 45-degree COD trial time shared similar coefficient of determinations with MDJ distance (51.3 and 51.8%, respectively) and MDJ plant-step variables (42.1% and 54.0%, respectively).

Discussion

The main finding of this study was faster COD trial times were associated with task-specific performance (i.e. plant-step kinetics) variables that distinguished faster and slower individuals. Previous research has demonstrated specificity of force exertion during various COD tasks (Schot et al., 1995; Sigward, Cesar, & Havens, 2014; Spiteri et al., 2015; Suzuki et al., 2014). Comparing plant-step kinetics of 90-degree and 45-degree COD manoeuvres, Schot and colleagues (1995) found a significant difference in relative mean propulsive force (ES = 1.02) and relative mean vertical force (ES = -0.58) between tasks. Similarly, Spiteri and co-workers (2015) observed a significant difference in relative vertical propulsive force during the 505 test when faster and slower individuals were compared (ES = 1.72, $p \leq 0.02$). The present study showed individuals with faster 180-degree COD performances exerted more absolute and relative mean force in the anterior-posterior (Fy) and vertical (Fz) planes than their slower counterparts. Likewise, individuals with faster 45-degree COD performances exerted more absolute and relative mean force in the medial-lateral (Fx) and vertical (Fz) planes than their slower counterparts.

These specific relationships are readily explained by the task objective. During a 180-degree COD manoeuvre, motion will be primarily expressed along the anterior-posterior axis – that is, a straight-line sprint, plant and turn in the opposite direction, followed by a straight-line sprint. During a 45-degree COD manoeuvre, motion will incorporate force expressed along the medial-lateral axis – that is, a straight-line sprint, plant and ‘cut’ to the contralateral side, followed by a straight-line sprint. The similar association

z-axis measures share with 180-degree and 45-degree COD performance can be explained by the role vertical force has in resisting negative acceleration due to gravity to maintain posture during the weight acceptance phase of high-speed locomotion (Enoka, 2008).

Also of interest was the novel examination of the relative contribution of x-, y- and z-axis force to generated net force during the COD plant-step. Interestingly, only 180-degree COD performance was associated with this measure, with the y-axis relative contribution explaining 52.3% of shared variance. Why this measure was exclusive to 180-degree COD performance is unknown. However, this task-specific observation may be explained by dissimilar changes in velocity associated with each COD task. Specifically, the 180-degree COD task requires more change in sprint direction and sprint speed than the 45-degree COD task. The larger magnitudes of direction and speed change within the 180-degree COD tasks may decrease the variability in associated activities, such as sprint path and foot placement, primarily due to the greater COD angles necessitating a complete halt prior to sprinting in the opposite direction. It is suspected the lower speed 180-degree COD manoeuvre influenced more consistent actions throughout the task, thus allowing a clearer indication of statistical relationships. That is, the less 'noise' (variation) a task possesses, the clearer the indication of statistical relationships. Previous reports suggest movement variability is inherent in tasks requiring high-speed stretch-shortening coupled muscle actions (Condello, Kernozek, Tessitore, & Foster, 2016; Keller et al., 1996; Neto, Lindheim, de Miranda Marzullo, Baweja, & Christou, 2012; Preatoni et al., 2013; Schot et al., 1995; Weyand, Sternlight, Bellizzi, & Wright, 2000). Schot and colleagues (1995) suggested COD tasks that allow greater sprint speeds would likely be associated with greater within- and between-individual variation. Consequently, the authors suspected within- and between-individual variation contributed to the lack of association between some z-axis force measures and performance in 90-degree and 45-degree COD tasks (Schot et al., 1995). Recently, Preatoni and colleagues (2013) noted the replication of the same movement will encompass a certain amount of movement and coordination variability, particularly in high-speed tasks. The authors also noted this inevitable unwanted "error" can hinder the description of athletic movements and the detection of relative statistical relationships (Preatoni et al., 2013). Bartlett et al. (2007) also noted this inherent movement variability is evident regardless of training age or experience (e.g. novices vs. experts). Due to findings of the high-speed video in Chapter 3, video of the current

study was inspected. Similarly this suggested high within- and between-individual variation in selecting approach and exit paths, braking strategy (e.g. position and placement of the penultimate step), and flexion and extension of the trunk, hip and knee between 180-degree and 45-degree COD tasks. Though these observations are anecdotal, and thus speculative, they support previous reports concerning movement variability.

Another interesting finding was the exclusive relationship x-axis and z-axis RFD had with 45-degree COD task. Similar to aforementioned observations, this exclusive association with RFD may again be explained by differences in velocity change between COD tasks. The faster sprint speeds and the more modest angle of direction change afford shorter GCT. The shorter GCT may in turn place a specific demand on force capabilities rather than force capacity (Bourgeois, Gamble, Gill, & McGuigan, 2017; Suchomel et al., 2016) (Chapter 2). That is, the shorter time intervals allotted by more rapid COD tasks may emphasise the rate at which force is developed as opposed to the magnitude of force developed (Bourgeois et al., 2017; Suchomel et al., 2016; Wang et al., 2016) (Chapter 2). Between-task comparison of relative mean Fy and Fz RFD supports this posit. Specifically, relative mean Fy RFD showed trivial (ES = 0.18) and small (ES = 0.35) differences between left- and right-leg 180-degree and 45-degree COD tasks, while Fz RFD showed large (ES = 1.97) and very large (ES = 2.19) differences between left- and right-leg 180-degree and 45-degree COD tasks, respectively.

Shorter GCT during the COD plant-step has been associated with faster performances in various COD tasks (Dos'Santos, Thomas, Jones, & Comfort, 2017; Green et al., 2011; Miller et al., 2006; Sasaki et al., 2011; Spiteri et al., 2015; Theiss et al., 2014). Though small differences (ES = 0.29) in GCT have been reported between executing a 90-degree COD task using different manoeuvres (side-step vs. crossover step) (Suzuki et al., 2014), large differences have been reported between COD tasks (Spiteri et al., 2015). Spiteri and colleagues (2015) showed fast (n= 6) and slow (n = 6) individuals each had large differences between 505 and T-test GCT (ES: fast group = -1.42 and slow group = -1.31). Therefore, the very large differences (ES = -3.73) in plant-step GCT between 180-degree and 45-degree COD tasks were expected. In order to change sprint direction individuals must reposition body segments, and thus centre of mass, for the new direction (Jindrich, Besier, & Lloyd, 2006; Spiteri et al., 2013). The time to execute this whole-body repositioning during the plant-step will be task-dependent, and

governed by sprint direction and speed (Hader, Palazzi, & Buchheit, 2015; Spiteri et al., 2015) (Chapter 2). Specifically, tasks that require large angles of direction change (e.g. 180-degree COD) will require more time to reposition the body for motion in the opposite direction. Conversely, tasks that require more modest angles of direction change (e.g. 45-degree COD) will require less time to reposition the body due to the more straight-line sprint path.

Of interest was the report of measures associated with the MDJ developed in this thesis. Current literature advocates the use of multidirectional jumping when aiming to enhance COD capabilities (Brughelli et al., 2008; Green et al., 2011; Sheppard et al., 2014) (Chapter 2). The favourable relationships absolute and relative MDJ distance had with faster performances in 180-degree and 45-degree COD tasks support the findings and recommendations of the thesis. Chapter 2 provided the theoretical framework for developing the individualised MDJ, and Chapter 3 investigated the reliability and predictive capabilities of the individualised MDJ task designed to model a cutting action observed in invasion sports.

A novel finding was the GCT:distance and its relationship with 45-degree COD performance. This MDJ measure was used to investigate the relationship MDJ stance-phase GCT relative to jump distance has with 45-degree COD capabilities. The findings demonstrate MDJ GCT:distance successfully distinguished individuals in cutting tasks at speed. The consistent observation of faster individuals possessing a lower ratio (i.e. lower GCT and greater jump distance) suggests faster individuals in the 45-degree COD tasks jumped further with shorter ground contacts during the MDJ task. The ability to execute complex movements maximally in shorter times is a highly regarded athletic characteristic (Coh & Mackala, 2013; Suchomel et al., 2016; Winter et al., 2016).

Douglas and colleagues (2017) recently demonstrated highly trained sprinters exhibited shorter GCT and longer flight times during DJ when compared to non-sprint trained individuals. The authors also noted very large between-group differences in reactive strength indices (i.e. flight time:contact time). Previous investigations have observed certain kinematic factors (i.e. time and displacement) to distinguish individuals according to COD capabilities (Green et al., 2011). Notably, Green and colleagues (2011) investigated kinematic factors within a 45-degree COD task that distinguish semi-professional rugby league starters and non-starters. Key discriminating factors were plant-leg contact time (ES = dominant leg: 0.98 and non-dominant leg: 0.64),

push-off leg contact time (ES = dominant leg: 0.98 and non-dominant leg: 0.87) and push-off leg extension time (ES = dominant leg: 1.17 and non-dominant leg: 1.72) (Green et al., 2011). Recently, the validity of using total time to complete a COD test (e.g. 505 test) as the performance measure has been challenged (Arshi, Nabavi, Mehdizadeh, & Davids, 2015; Cuthbert, Thomas, Dos'Santos, & Jones, 2017; Nimphius et al., 2017; Nimphius, Callaghan, Spiteri, & Lockie, 2016). Alternative measures, such as COD deficit, have been proposed as more appropriate for assessing performance in COD tasks (Cuthbert et al., 2017; Nimphius et al., 2017). In accordance, the MDJ GCT:distance may offer practitioners a practical tool for testing and monitoring performance in cutting tasks, similar to the 45-degree COD in this study.

In the context of Newtonian physics discussed in Chapter 2, MDJ GCT:distance may serve as an indirect measure of an individual's impulse capabilities (Coh & Mackala, 2013). The utility of the MDJ GCT:distance measure in this function is supported by the impulse-momentum relationship which predicts the change in momentum will be proportionate with the force exerted over contact time. However, further investigation is required to support this proposal. More research is needed to confirm the current findings in more homogeneous groups, in addition to determining the measures associated with performance prediction in tasks that include lower contextual interference (e.g. the 45-degree COD) and higher contextual interference (e.g. receiving a pass at-speed and executing a cutting manoeuvre to evade two defenders). Potential findings would give practitioners a practical measure of neuromuscular capabilities pertinent to athletic movement, and provide a reliable assessment to monitor neuromuscular capabilities.

This appears to be the first study to examine the relationship between respective axis-specific measures in COD tasks and individualised MDJ manoeuvres thought to be effective in improving COD capabilities. Strong associations were found between COD and MDJ performance variables within the same plane of motion. Specifically, faster 180-degree COD performances were largely associated with absolute and relative MDJ distance, absolute and relative mean Fx, relative mean Fy and relative contribution of x-, y- and z-axis force to net force. Faster 45-degree COD performance was largely associated with absolute and relative MDJ 2.5 × leg length distance, MDJ 2.5 GCT:distance ratio, and MDJ 2.5 relative mean Fx. These findings agree with reports of strong relationships between horizontal jump measures and sprinting tasks (Dobbs, Gill, Smart, & McGuigan, 2015). In a cohort of slightly older rugby athletes, Dobbs and co-

workers (2015) found kinetics of unilateral horizontal CMJ and DJ possessed superior correlation to their vertical counterparts when 5 m sprint performance was examined. Collectively, these findings suggest 180-degree and 45-degree COD tasks and MDJ tasks, particularly MDJ × 2.5 leg-length, share more similar constraints and determinants. This association further suggests the use of MDJ tasks may provide greater 'transfer' to 180-degree and 45-degree COD performance.

Practical Applications

Force and force-time capabilities are considered essential in executing rapid changes in sprint direction. Understanding the association force capabilities have with COD tasks and proposed training modes will increase the likelihood of positive performance outcome by providing practitioners insight in exercise selection and training scheduling. The significant finding of this study was faster COD performances were related to task-specific kinetic variables that distinguished faster and slower individuals. Equally, MDJ performance measures were associated with the distinction between faster and slower 45-degree COD performances. The individualised MDJ could be used to improve COD capabilities, notably 45-degree COD performance. Before incorporating into the training plan, practitioners are advised to ensure individuals have sufficient strength capacities and technical capabilities before implementing this jump training. It is also recommended practitioners establish reliability and correlation statistics of MDJ and COD performance measures within the athletes to be trained.

Chapter 5 – Relationships between Strength, Speed-strength and Performance in Change of Direction Tasks

Overview

In Chapter 2 the rationale for investigating category-specific differences in performance measures was established. Justification for determining the relationship strength capacity and capabilities have with performance in COD tasks was also provided. Categorical differences between fast and slow individuals coupled with the strong association COD times shared with COD plant-step and MDJ stance-phase kinetics in Chapter 4 prompted further investigation of these relationships in a more homogeneous group. Therefore, the primary aim of this chapter was to examine categorical differences (i.e. forwards vs. backs) in measures of 180-degree and 45-degree COD performance in football code athletes. The second aim was to examine categorical differences in unilateral strength and speed-strength measures. The last aim was to identify the relationships between strength and speed-strength measures and 180-degree and 45-degree COD performance. The theoretical significance of identifying categorical differences in strength, speed-strength and COD performance measures would be affirmation of noted physical characteristics that distinguish sub-groups of individuals. Examining categorical differences in these performance measures would offer insight into the relationship between task and sub-group, and thus provide practical significance. This information could be used to guide group-specific exercise selection and scheduling within the training plan.

Introduction

Force generation capacity, or strength of an athlete, is widely accepted as foundational for injury prevention and athletic development (Suchomel et al., 2016). More important, the ability to effectively use generated force in a task-specific manner, such as jumping and receiving a contested pass, is considered critical for athletic success (Suchomel et al., 2016) (Chapter 2). Both strength and the proficient use of force can be distinguishing factors among football codes, such as rugby union (Kobal et al., 2016; Quarrie & Wilson, 2000; Negrete & Brophy, 2000), rugby league (Baker, 2002; Gabbett & Seibold, 2013) and American football (Garstecki, Latin, & Cuppett, 2004; Zvijac, Toriscelli, Merrick, Papp, & Kiebzak, 2014).

Across football codes there are data indicating trivial position-specific (e.g. wingers vs. hookers) and broader categorical (i.e. forwards vs. backs) differences in performance tests (Comfort, Graham-Smith, Matthews, & Bamber, 2011; Kirkpatrick & Comfort, 2013; Meir, Newton, Curtis, Fardell, & Butler, 2001). Equally, measures of anthropometry (height and mass) (Gabbett, Jenkins, & Abernethy, 2011; Meir et al., 2001), upper- and lower-body strength (Brown, Brughelli, & Bridgeman, 2016; Meir et al., 2001), speed-strength (Brechue, Mayhew, & Piper, 2010), strength endurance (Meir et al., 2001) and straight-line speed (Brechue et al., 2010; Gabbett & Seibold, 2013; Meir et al., 2001) have demonstrated differences between forwards and backs. Of interest are the relationships between unilateral strength, speed-strength, and COD times among football code forwards and backs.

Several reports have examined categorical differences in performance tests among athletes in different football codes (Baker, 2002; Comfort et al., 2011; Gabbett et al., 2008; Gabbett & Seibold, 2013; Garstecki et al., 2004; Kirkpatrick & Comfort, 2013; Kobal et al., 2016; Meir et al., 2001; Murtagh et al., 2017; Shillabeer, Mills, & Goodwin, 2015; Vescovi & McGuigan, 2008; Zvijac et al., 2014). However, there are limited reports comprehensively examining the association isometric and isokinetic strength, and multidirectional CMJ and DJ ability have with performance in COD tasks that require larger and more modest changes in velocity (direction and speed).

It is proposed that a relationship exists between lower-limb strength and performance in COD tasks (Brughelli et al., 2008; Sheppard et al., 2014; Suchomel et al., 2016) (Chapter 2). Recently, bilateral isometric (Shillabeer et al., 2015; Spiteri et al., 2013; Wang et al., 2016) and dynamic (Delaney et al., 2015; Spiteri et al., 2014) strength

measures have been associated with performance in COD tasks. The relationship isokinetic strength has with performance in COD tasks has also been investigated, yielding equivocal results (Lockie et al., 2012; Negrete & Brophy, 2000). Reports comparing specific relationships unilateral isometric and isokinetic strength have with performance in tasks that require large and more modest direction changes is sparse. Likewise, more research exploring categorical differences in isometric and joint-specific isokinetic measures among football code athletes is needed.

Single-effort jump performance along vertical, horizontal and lateral axes has been proposed to benefit performance in COD tasks (Brughelli et al., 2008; Sheppard et al., 2014) (Chapter 2). Though previous research has demonstrated these unilateral single-effort jumps to be positively associated with linear sprint speed (Dobbs et al., 2015; Holm, Stalbom, Keogh, & Cronin, 2008; Lockie, Schultz, et al., 2014), these studies did not examine the relationship between unilateral jump ability and COD ability (Dobbs et al., 2015; Holm et al., 2008; Murtagh et al., 2017), or accentuated unilateral jump performance along the medial-lateral axis (Delaney et al., 2015; Kobal et al., 2016; Los Arcos, Mendiguchia, & Yanci, 2017; Murtagh et al., 2017). Current data suggests horizontal (i.e. anterior-posterior and medial-lateral axes) jump measures have greater association with athletic movements in the horizontal plane compared to their vertical counterparts (Brughelli et al., 2008; Dobbs et al., 2015). Also, data demonstrating ground reaction forces differ between COD tasks executed at speed (Schot et al., 1995; Spiteri et al., 2013) suggests the need to investigate the task-specific relationships anterior-posterior and medial-lateral speed-strength measures have with COD tasks differing in magnitudes of velocity change. Furthermore, there is a paucity of research examining the category-specific relationship unilateral speed-strength has with executing COD tasks among football code forwards and backs.

The primary purpose of this study was to examine categorical differences (i.e. forwards vs. backs) in COD, strength and speed-strength measures. The second purpose was to investigate the relationships between task-specific COD performance and unilateral strength and speed-strength measures. It was hypothesised backs would produce better scores in COD and speed-strength measures while forwards would score higher in strength measures. Also hypothesised was 180-degree COD performance would have greater association with strength measures while 45-degree COD performance would have greater association with speed-strength measures.

Methods

Experimental approach to the problem

A cross-sectional design was used to investigate relationships between strength, speed-strength and COD measures in football code athletes. Testing was conducted over two days separated by a minimum of 24 hours. Day 1 testing consisted of COD and jump testing, and Day 2 strength testing. Testing was performed during the same time of day to control diurnal effects.

Subjects

Twelve males (age: 22.4 ± 3.1 yr; body mass: 92.1 ± 7.4 kg; height: 1.8 ± 0.1 m) volunteered for this investigation. The cohort consisted of club-level rugby union (n = 10) and American football (n = 2) athletes. Inclusion criteria were a minimum training age of five years and a minimum training schedule of one hour of structured, deliberate resistance and sports training three days·week^{-1}. Forwards of rugby union and American football were defined as players involved in the scrum or typically involved with contests against linemen, respectively. Backs of rugby union and American football were defined as players not in the scrum or not typically involved with contests against linemen, respectively. Each participant had the benefits and risks of the investigation explained verbally and in written form, and signed an informed consent form before participation. The Auckland University of Technology Ethics Committee approved all procedures undertaken in this study (15/322).

Procedures

All participants were instructed to refrain from unusual or vigorous resistance exercise and cardiovascular activity 48 hours prior to testing. However, volunteers continued usual training routines to control performance changes due to a sudden change in physical activity. Prior to testing, body mass and height were measured using a calibrated digital scale (HW-200KGL, CA, USA) and stadiometer (Holtain limited, Harpenden, Wales, UK), respectively. The order of COD assessment and COD plant-leg were randomised and counterbalanced with assessment (180-degree vs. 45-degree COD) and plant-leg (right-leg vs. left-leg) selected and ordered by blinded drawing. The testing schedule was as follows: Day 1, COD and jump testing; Day 2, strength testing. Each testing battery was preceded by a standardised warm-up and identical tests described below, in the same order. The warm-up consisted of five minutes of

submaximal cycling followed by five minutes of multi-joint dynamic stretching. Each participant was instructed to execute two maximum effort familiarisation trials prior to testing trials (excluding eccentric isokinetic strength testing). Neither verbal encouragement nor technical cueing was given. Also, all participants wore the same athletic shoes for both testing sessions.

Change of direction assessment

Change of direction capabilities in tasks that require relatively larger and more modest direction changes were assessed using 180-degree and 45-degree manoeuvres, respectively (Figure 3.1). Protocol details can be found in Chapter 3. Briefly, five attempts per assessment were given for both left and right plant-legs with two min rest between each trial. Variables of interest were approach sprint times (i.e. sprint time prior to the COD-step), exit sprint times (i.e. sprint time after the COD-step) and total sprint time. The COD-step was defined as the plant-step that completed the change in sprint direction, characterised by the greatest magnitude of weight-acceptance and propulsion in the new direction. Within-session reliability of left and right 180-degree approach, exit and total time were: CV = 2.4 and 2.4%, 4.2 and 3.1%, 0.9 and 1.6%, respectively. Reliability of left and right 45-degree COD measures were: CV = 2.7 and 2.7%, 2.5 and 2.2%, 2.0 and 1.8%, respectively.

Jump assessment

Following a 10 min rest and familiarisation, participants executed maximal effort bilateral vertical squat jump (SJ) and CMJ as a warm-up. Next, participants tested in unilateral vertical, horizontal (anteriorly) and lateral (medially) CMJ and 30 cm DJ. Two attempts per leg with approximately 30 s rest between each trial were allotted. Tape was used to standardise the start position (CMJ) and landing area (DJ) in the centre of the force plate. A custom-built platform was juxtaposed to the force platform to ensure participants landed on a surface level with their jump position. Arm swing and the non-jump leg were not restricted. Arm swings were allowed to increase ecological validity, as jumps executed in competition generally include unrestricted arms. Furthermore, force-time traces and high-speed video during pilot testing revealed a faster rate of familiarisation when arms were unrestricted, particularly during DJ. Nonetheless the start position of the arms was standardised to full extension with hands above the head. A trial was excluded and reattempted if the following was observed:

preliminary movement, poor technique, foot contact outside of the designated area on the force plate, submaximal effort or poor landing.

Vertical CMJ began with the non-jump leg flexed approximately 90 degrees at the knee, hip and ankle. When ready participants self-selected the countermovement depth and jumped vertically as high as possible landing on both feet.

Horizontal CMJ began with the non-jump leg flexed approximately 90 degrees at the knee, hip and ankle. When ready participants self-selected the countermovement depth and jumped horizontally (anteriorly) as far as possible landing on both feet.

Lateral CMJ began with the non-jump leg flexed approximately 90 degrees at the knee, hip and ankle. When ready participants self-selected the countermovement depth and jumped laterally (medially) as far as possible landing on both feet.

Drop jumps began identically to CMJ, however participants dropped from the 30 cm box and jumped vertically, horizontally or laterally for maximum displacement landing on both feet simultaneously. All participants were instructed to "drop from the box and achieve maximum height following a short contact time".

A portable AMTI triaxial force plate (AccuPower, Advanced Mechanical Technologies, Newton, MA, USA) using custom-built LabVIEW program (Version 14.0, National Instruments Corp, Austin, TX, USA) was used to collect stance-phase force-time data at 1000 Hz. Kinetic data were collected from a threshold of 30 N, normalised to body weight, and filtered with a 4th order 200 Hz low-pass Butterworth filter.

A high-speed digital camera (Casio, Exilim EX-FH20, Tokyo, Japan) was used for qualitative (technique) and quantitative (jump distance) analysis of each jump. Vertical jump height was calculated using the LabVIEW program. Video collected at 120 frames·s^{-1} was imported into a commercially available kinematic analysis software (Kinovea, version 0.8.15) to determine horizontal and lateral jump distance. Horizontal jump distance was measured from the toe of the jump-foot to the heel closest to the start line. Lateral jump distance was measured from the medial side of the jump-foot to the lateral side of the jump foot. All jump displacements were recorded to the nearest 0.01 m. The software was calibrated using a 0.70 m marking parallel to the jump path. Variables of interest were movement time (i.e. initial movement (CMJ) or toe-down (DJ) to toe-off), vertical (z-axis) and horizontal (y- and x-axis summation) mean and

peak eccentric and concentric force, impulse, take-off velocity, and mean jump distance. Within-session reliability for these measures is shown in Table 5.1.

Table 5.1. Within-session reliability of countermovement and drop jump measures.

Countermovement jump measure coefficients of variation

Measurement	Vertical		Horizontal		Lateral	
	Left-leg	Right-leg	Left-leg	Right-leg	Left-leg	Right-leg
Displacement (m)	14.36	7.92	11.79	6.61	11.59	73.99
Positive impulse (N·s)*	1.11	1.06	6.43	3.69	1.63	2.05
Negative impulse (N·s)*	32.52	26.81	26.59	34.05	26.21	33.56
Net impulse (N·s)	2.30	1.15	3.40	3.09	3.99	4.27
Vertical take-off ($m \cdot s^{-1}$)	16.62	8.81	51.26	63.85	134.52	79.81
Horizontal impulse (N·s)	n.c.	n.c.	39.81	6.18	3.95	1.99
Horizontal take-off ($m \cdot s^{-1}$)	n.c.	n.c.	1.99	31.34	84.10	31.41

Drop jump measure coefficients of variation

Measurement	Vertical		Horizontal		Lateral	
	Left-leg	Right-leg	Left-leg	Right-leg	Left-leg	Right-leg
Displacement (m)	25.69	7.36	7.88	4.70	17.74	13.65
Eccentric time (s)	3.53	6.82	n.c.	n.c.	n.c.	n.c.
Concentric time (s)	26.62	31.51	n.c.	n.c.	n.c.	n.c.
Peak eccentric force ($N \cdot N^{-1}$)	1.17	1.42	n.c.	n.c.	n.c.	n.c.
Mean eccentric force ($N \cdot N^{-1}$)	0.49	0.93	n.c.	n.c.	n.c.	n.c.
Peak concentric force ($N \cdot N^{-1}$)	0.62	1.07	n.c.	n.c.	n.c.	n.c.
Mean concentric force ($N \cdot N^{-1}$)	0.37	0.57	n.c.	n.c.	n.c.	n.c.
Positive impulse (N·s)*	0.87	0.87	0.75	0.66	0.76	0.94
Negative impulse (N·s)*	1.02	1.18	21.71	18.36	12.25	26.59

Net impulse (N·s)	0.48	0.62	2.97	0.69	0.83	0.63
Vertical take-off ($m \cdot s^{-1}$)	6.81	7.44	6.92	3.53	4.42	3.80
Horizontal impulse (N·s)	n.c.	n.c.	7.34	18.37	8.51	16.72
Horizontal take-off ($m \cdot s^{-1}$)	n.c.	n.c.	68.69	49.16	53.89	157.66

* = z-axis measurement, coefficient of variation = typical error as percentage of mean, n.c. = measure not calculated.

Strength assessment

Isometric unilateral back squat was performed on a uniaxial force plate (Model: 400S Isotronic Force Plate, Fitness Technology, South Australia, Australia) sampling at 600 Hz to assess maximum lower body strength. Once the centre of mass was positioned over the support-leg, a goniometer was used to set the support hip and knee at 140 degrees, while the non-support knee remained flexed at 90 degrees. The support-leg was randomised and counterbalanced. First, volunteers performed one familiarisation trial at self-selected 75% and 90% intensities. Next three five-second test trials were performed on each leg with two min rest between each trial. The variable of interest was peak force normalised to body weight (N). Intra-individual within-session reliability for left- and right-leg peak normalised force in this cohort ranged from CV = 2.3 to 6.4% and 2.3 to 6.3%, respectively.

Unilateral eccentric and concentric isokinetic strength of the hip and knee were measured with a Humac Norm dynamometer (Lumex, Ronkonkoma, NY, USA). Following familiarisation each participant executed ipsilateral then contralateral extension and flexion in one orientation (e.g. seated knee assessment), followed by ipsilateral and contralateral extension and flexion in the second orientation (e.g. supine hip assessment) (Brown et al., 2016). Each leg was first assessed at a fixed angular velocity of 180°/s for 5 extensions and 5 flexions for the knee and hip at 100 Hz. Lastly, each leg was assessed at a fixed angular velocity of 60°/s for 5 extensions and 5 flexions for the knee and hip at 100 Hz. Two min rest was given between trials. It should be noted 60°/s eccentric data were not collected for hip extension and flexion due to rapid fatigue accumulation in the relatively small musculature of the hip flexor complex. Pilot testing showed this acute fatigue made it difficult to differentiate physiological capacities from strength capacities; thus 60°/s eccentric data were eliminated. Variables of interest were joint-specific peak torque, and torque-angle profiles. Intra-individual within-session reliability for hip concentric measures and knee eccentric and concentric measures were CV = 0.8 to 28.6%, 0.8 to 23.6% and 1.8 to 39.0%, respectively.

Statistical analysis

Central tendency and dispersion of the data were calculated for all variables as mean ± SD. All data were log transformed to reduce non-uniformity of error (Hopkins, 2000) with mean scores used for analysis. Typical error of measurement was used to express variability as a percentage of the between-trial mean (CV). Unpaired *t*-tests were used to

compare categories (forwards vs. backs). Statistical significance was set at $p \leq 0.05$. Pearson's correlation (r) was used to quantify relationships strength and speed-strength measures have with COD times. Correlation thresholds for nearly perfect, very large, large, moderate, small and trivial were 0.9, 0.7, 0.5, 0.3, 0.1 and <0.1, respectively (Hopkins, 2000). Coefficient of determination (r^2) was also reported to describe shared variation between performance measures.

Results

Change of direction assessment

Table 5.2 shows the results for COD assessments.

180-degree change of direction performance

The left-leg manoeuvre showed forwards were moderately slower than backs in approach time (difference in mean (DIM) = -36.3%, ES = -0.88, p = 0.20), exit time (DIM = -32.1%, ES = -0.76, p = 0.22) and total time (DIM = -3.5%, ES = -1.12, p = 0.79).

The right-leg manoeuvre showed a small difference between forwards and back in approach time (DIM = -19.7%, ES = -0.50, p = 0.41). However, forwards were moderately slower in exit time (DIM = -37.7%, ES = -0.71, p = 0.27) and total time (DIM = -1.84%, ES = -0.78, p = 0.21).

45-degree change of direction performance

The left-leg manoeuvre showed forwards were slower than backs in approach time (DIM = -441.1%, ES = -1.40, p = 0.04), exit time (DIM = -38.3%, ES = -2.03, p = 0.01) and total time (DIM = -17.3%, ES = -2.27, p = 0.00).

The right-leg manoeuvre showed forwards were slower in approach time (DIM = -400.6%, ES = -1.35, p = 0.04), exit time (DIM = -32.7%, ES = -2.00, p = 0.02) and total time (DIM = -15.0%, ES = -2.15, p = 0.01).

Table 5.2. Between-category and between-task comparisons of performance in change of direction tasks.

	180-degree change of direction tasks			45-degree change of direction tasks		
Measure	Forwards (n = 6)	Backs (n = 6)	ES	Forwards (n = 6)	Backs (n = 6)	ES
Left-leg approach time (s)	1.12 ± 0.09	1.07 ± 0.01‡	-0.88	1.02 ± 0.09	0.94 ± 0.03*	-1.40
Left-leg exit time (s)	1.07 ± 0.03	1.05 ± 0.03‡	-0.76	0.74 ± 0.03	0.66 ± 0.05**	-2.03
Left-leg total time (s)	2.75 ± 0.11	2.65 ± 0.07‡	-1.12	1.76 ± 0.08	1.60 ± 0.07**	-2.27
Right-leg approach time (s)	1.12 ± 0.06	1.09 ± 0.03‡	-0.50	1.02 ± 0.07	0.95 ± 0.04*	-1.35
Right-leg exit time (s)	1.07 ± 0.03	1.04 ± 0.04‡	-0.71	0.73 ± 0.02	0.66 ± 0.05*	-2.00
Right-leg total time (s)	2.73 ± 0.06	2.68 ± 0.06‡	-0.78	1.75 ± 0.06	1.61 ± 0.07**	-2.15

* = significant difference between forwards and backs, $p \leq 0.05$, ** = significant difference between forwards and backs, $p \leq 0.01$, † = significant difference between 180-degree and 45-degree performance, $p \leq 0.05$, ‡ = significant difference between 180-degree and 45-degree performance, $p \leq 0.01$.

Unilateral jump assessment

Vertical jump performance

Left- and right-leg CMJ absolute height revealed a large categorical difference with forwards outperforming backs (DIM = 13.3% and 8.2%, ES = 1.47 and 1.33, p = 0.03 and 0.05, respectively). Left- and right-leg DJ absolute height revealed a moderate difference with backs outperforming forwards (DIM = 79.6% and 12.8%, ES = 0.89 and 0.66, p = 0.33 and 0.37, respectively).

Horizontal jump performance

Absolute jump distance revealed a trivial difference between forwards and backs in left- and right-leg CMJ (DIM = -0.5% and 0.6%, ES = -0.02 and 0.02, p = 0.98 and 0.97, respectively). Similarly, there was a small difference between forwards and back in left- and right-leg DJ (DIM = 7.2% and -9.6%, ES = 0.27 and -0.24, p = 0.68 and 0.74, respectively).

Lateral jump performance

Absolute jump distance showed a trivial difference between forwards and backs in left-leg CMJ (DIM = -2.7%, ES = -0.08, p = 0.91). Conversely, forwards jumped shorter distances in right-leg CMJ (DIM = 39.8%, ES = 0.63, p = 0.30). There was a trivial difference in left-leg DJ (DIM = 6.3%, ES = 0.11, p = 0.87) and a small difference in right-leg DJ (DIM = 22.6%, ES = 0.37, p = 0.57).

Isometric strength assessment

Small differences between forwards and backs were observed in left- and right-leg relative strength (DIM = 9.2% and 6.9%, ES = 0.59 and 0.44, p = 0.35 and 0.48, respectively).

Table 5.3. Between-category and between-task comparison of unilateral isometric strength.

Measure	Forwards (n = 6)	Backs (n = 6)	ES
Relative left-leg strength ($N \cdot N^{-1}$)	3.3 ± 0.8	3.6 ± 0.3	0.59
Relative right-leg strength ($N \cdot N^{-1}$)	3.4 ± 0.9	3.6 ± 0.4	0.44

Isokinetic strength assessment

Results are shown in Table 5.4.

Hip concentric torque-angle profile comparison

Left-leg extension at 60°/s showed a categorical difference in peak torque angle with forwards performing at greater angles (DIM = -0.9%, ES = -0.85, p = 0.19). Flexion at 60°/s showed a difference in peak torque with backs outperforming forwards (DIM = 4.1%, ES = 0.76, p = 0.24). A difference in flexion peak torque angle was observed with forwards performing at greater angles (DIM = -5.6%, ES = -1.09, p = 0.09).

Left-leg extension at 180°/s revealed a difference in peak torque with forwards outperforming backs (DIM = -232.4%, ES = -1.75, p = 0.20). A difference was observed in peak torque angle with forwards performing at greater angles (DIM = -182.6%, ES = -0.65, p = 0.41). Right-leg extension peak torque and peak torque angle each showed forwards outperforming backs (DIM = -103.1% and -191.7%, ES = -0.80 and -0.83, p = 0.23 and 0.28, respectively). Flexion at 180°/s showed a difference in peak torque with backs outperforming forwards (DIM = 81.6%, ES = 0.88, p = 0.16).

Knee concentric torque-angle profile comparison

Left-leg extension at 60°/s revealed a difference in peak torque angle with forwards performing at greater angles (DIM = -0.7%, ES = -0.63, p = 0.31).

Left-leg flexion at 180°/s showed a difference in peak torque angle with forwards performing at greater angles (DIM = -2.2%, ES = -0.65, p = 0.31). Right-leg flexion at 180°/s showed a difference in peak torque with forwards performing at greater angles (DIM = -6.0%, ES = -1.04, p = 0.16).

Table 5.4. Between-category and between-task comparison of peak hip concentric torque-angle profiles.

	180°/s (concentric)			60°/s (concentric)		
Measure	Forwards	Backs	ES	Forwards	Backs	ES
Hip peak torque (N·m)						
left-leg extension	169.1± 51.7	84.3 ± 43.9*‡	-1.75	238.8 ± 65.8	211.7 ± 71.5	-0.41
right-leg extension	176.5± 64.8	123.6 ± 74.7‡	-0.80	254.4 ± 57.9	227.2 ± 41.8	-0.46
left-leg flexion	151.6± 57.8	144.4 ± 41.4	-0.11	153.6 ± 39.3	191.6 ± 62.6	0.76
right-leg flexion	120.7 ± 54.3	179.4 ± 89.5	0.88	149.2 ± 53.6	189.9 ± 102.1	0.39
Hip peak angle (°)	Forwards	Backs	ES	Forwards	Backs	ES
left-leg extension	66.9 ± 4.1	61.5 ± 13.9†	-0.65	75.2 ± 3.1	72.4 ± 3.6	-0.85
right-leg extension	65.2 ± 4.9	58.0 ± 13.0‡	-0.83	72.8 ± 4.1	71.1 ± 5.2	-0.38
left-leg flexion	30.8 ± 4.3	31.4 ± 3.7‡	0.16	26.0 ± 6.5	21.3 ± 2.9	-1.09
right-leg flexion	30.3 ± 8.0	28.5 ± 4.6‡	-0.22	23.9 ± 5.6	23.5 ± 3.4	0.09

* = significant within-task difference between forwards and backs, $p \leq 0.05$, ** = significant within-task difference between forwards and backs, $p \leq 0.01$,

† = significant between-task difference between 180°/s and 60°/s, $p \leq 0.05$, ‡ = significant between-task difference between 180°/s and 60°/s, $p \leq 0.01$.

Table 5.4 (cont.). Between-category and between-task comparison of knee peak concentric and eccentric torque-angle profiles.

Measure	180°/s (concentric)			60°/s (concentric)			60°/s (eccentric)		
Knee peak torque (N·m)	Forwards	Backs	ES	Forwards	Backs	ES	Forwards	Backs	ES
left-leg extension	144.9± 29.8	159.2 ± 51.7†	0.20	190.0 ± 49.5	216.0 ± 55.8	0.49	126.9± 41.7‡	157.4± 47.4	0.71
right-leg extension	167.8 ± 20.4	170.6 ± 43.5	-0.03	197.6 ± 58.8	213.9 ± 52.2	0.34	125.1± 42.9‡	152.0 ± 56.1	0.52
left-leg extension	83.5 ± 31.5	80.6 ± 41.5‡	-0.20	121.1 ± 33.0	125.7 ± 38.9	0.12	199.1 ± 61.3‡	238.8± 85.2	0.55
right-leg flexion	99.2 ± 14.3	79.1 ± 27.2†	-1.04	122.1± 29.0	114.2 ± 30.5	-0.25	209.5 ± 74.9‡	244.5± 97.3	0.41
Knee peak angle (°)	Forwards	Backs	ES	Forwards	Backs	ES	Forwards	Backs	ES
left-leg extension	56.4 ± 6.2	53.8 ± 8.2‡	-0.40	67.9 ± 4.4	65.8 ± 1.9	-0.63	39.8 ± 13.3‡	26.6± 4.7*	-1.49
right-leg extension	55.0 ± 6.7	53.0 ± 5.9	-0.31	61.0 ± 18.1	65.2 ± 3.3	0.53	28.7 ± 7.5‡	29.6 ± 13.9	-0.04
left-leg flexion	49.9 ± 5.8	46.0 ± 6.6‡	-0.65	26.8 ± 4.0	25.8 ± 4.9	-0.28	53.6 ± 14.7‡	59.8 ± 8.3	0.59
right-leg flexion	99.2 ± 14.3	79.1 ± 3.2‡	0.01	30.6 ± 11.0	28.4 ± 9.0	-0.22	54.9 ± 12.6‡	58.3 ± 9.3	0.34

* = significant within-task difference between forwards and backs, $p \leq 0.05$, ** = significant within-task difference between forwards and backs, $p \leq 0.01$, † = significant between-task difference between 180°/s and 60°/s, $p \leq 0.05$, ‡ = significant between-task difference between 180°/s and 60°/s, $p \leq 0.01$.

Knee eccentric torque-angle profile comparison

Left-leg extension at 60°/s showed a difference in peak torque with backs outperforming forwards (DIM = 4.7%, ES = 0.71, p = 0.25). A difference was observed in peak torque angle with forwards performing at greater angles (DIM = -10.2%, ES = -1.49, p = 0.03).

Interclass correlation

Unilateral CMJ and DJ measures showed significant association with approach time, exit time and total time of 180-degree and 45-degree COD tasks. First, correlation between COD performance and jumps that differ in task objective (i.e. CMJ vs. DJ) was analysed. Association between 180-degree COD performance and CMJ measures ranged from large to very large (r = -0.85 to -0.58, p = 0.00 to 0.05), while association with DJ measures also ranged from large to very large (r = -0.78 to -0.59, p = 0.00 to 0.05). Association between 45-degree COD performance and CMJ measures were very large (r = -0.71 to 0.70, p = 0.01 to 0.05), while association with DJ measures were also very large (r = -0.82 to 0.75, p = 0.00 to 0.05). Comparison of CMJ and DJ correlations with COD performance revealed CMJ measures were largely correlated with approach time (eight variables: r = -0.85 to -0.62, p = 0.00 to 0.03) and total time (12 variables: r = -0.81 to -0.58, p = 0.00 to 0.05), while DJ measures were largely correlated with exit time (18 variables: r = -0.82 to 0.75, p = 0.01 to 0.05).

Relationships between COD performance and jump test direction were analysed (i.e. vertical vs. horizontal vs. lateral). The most observations of significant association (22 total correlations) with COD performance was found with vertical plane measures, ranging from large to very large (r = -0.85 to -0.58, p = 0.00 to 0.05). The second most observations of significant association (4 total correlations) with COD performance was with horizontal (anterior-posterior) measures where large magnitudes were found (r = -0.58 to 0.67, p = 0.02 to 0.05). Lateral (medial-lateral) measures showed non-significant association with COD performance. Specifically, more observations of large correlation were found between vertical take-off velocity and negative vertical impulse and COD performance than any other jump measure. Eccentric vertical plane measures also showed more instances of large correlation with COD performance than their concentric and horizontal plane counterparts

(9 correlations: r = 0.60 to -0.81, *p* = 0.01 to 0.04 vs. 2 correlations: r = 0.59 and 0.67, *p* = 0.05 and 0.02, respectively).

Trivial to small non-significant correlation was found between left- and right-leg relative isometric strength and approach, exit and total times in COD tasks (r = -0.32 to 0.28, *p* = 0.32 to 0.94).

Conversely, isokinetic strength measures showed significant correlations with approach time, exit time and total time of 180-degree and 45-degree COD tasks. Joint-specific torque showed large association between hip concentric extension peak torque at 180°/s and COD performance (r = 0.62 to 0.68, *p* = 0.02 to 0.03). Hip concentric flexion torque at 180°/s showed moderate to large association with COD performance (r = -0.70 to -0.36, *p* = 0.01 to 0.03). Knee concentric flexion torque at 180°/s showed large to very large association with COD performance (r = 0.62 to 0.71, *p* = 0.01 to 0.03). Joint-specific peak torque angles showed large association between hip concentric extension peak torque angle at 180°/s and COD performance (r = 0.64, *p* = 0.03). Hip concentric extension and flexion peak torque angles at 60°/s each showed large to very large association with COD performance (r = 0.60 to 0.74, *p* = 0.01 to 0.04; and r = 0.61 to 0.64, *p* = 0.03 to 0.04, respectively). Knee extension and flexion concentric peak torque angles at 60°/s each showed large to very large association with COD performance (r = 0.60 to 0.74, *p* = 0.01 to 0.04; and r = -0.70 to 0.76, *p* = 0.00 to 0.01, respectively).

Discussion

The primary purpose of this study was to investigate categorical differences in measures of 180-degree and 45-degree COD performance in football code athletes. The second aim was to examine categorical differences in unilateral strength and speed-strength measures. Lastly, associations between strength and speed-strength measures with 180-degree and 45-degree COD performance were explored.

There are reports of COD tasks, namely the 180-degree COD manoeuvre, being unsuccessful in discriminating individuals (Brughelli et al., 2008; Gabbett et al., 2008; Sheppard et al., 2014). In accordance, the 180-degree COD task did not distinguish forwards and backs. However, the success of the 45-degree COD task in distinguishing forwards and backs suggests that COD tasks executed at higher speeds, and therefore more

modest direction changes, may be more appropriate in testing and monitoring performance in COD tasks of football code athletes. Contextually, COD tasks that require more modest direction changes will afford greater categorical differences due to the higher sprint speeds. These higher, more linear, sprint speeds would serve as a limiting factor separating player categories. This contention is supported by the success of linear sprint performance in distinguishing forwards and backs (Kirkpatrick & Comfort, 2013). More research is needed in exploring this posit in sport-specific and position-specific COD tasks.

Performance in strength tests has been shown to distinguish rugby codes (Brown, Brughelli, Griffiths, & Cronin, 2014) and categories of athletes (Brown et al., 2016; Comfort et al., 2011; Meir et al., 2001). Though there were not enough participants to conduct a between-code comparison, the current study supports categorical differences as moderate and large differences between forwards and backs were observed in concentric and eccentric isokinetic strength (ES = -1.75 to 0.88). Previous comparison of forwards and backs across football codes have demonstrated forwards generally produce greater torques than backs (Brown et al., 2016; Brown et al., 2014; Zvijac et al., 2014). The forwards and backs in this study were weaker and produced peak torque at smaller angles when compared to previously reported data on American football (Zvijac et al., 2014) and rugby union (Brown et al., 2016; Brown et al., 2014) athletes. Specifically, concentric knee extension peak torque at 60°/s revealed forwards and backs in this study were 76.7% and 39.8% weaker than their respective American football counterparts (Zvijac et al., 2014). Likewise, forwards and backs in this study were weaker than their rugby union counterparts of Brown et al. (2014) (41.6% and 23.8%, respectively) and Brown et al. (2016) (14.2% and 4.7%, respectively). Concentric knee flexion peak torque at 60°/s showed forwards and backs in this study were 91.1% and 71.5% weaker than their American football counterparts, respectively (Suchomel et al., 2016). Similarly, forwards and backs in this study were weaker than those of Brown et al. (2014) (49.7% and 30.5%, respectively). The forwards in this study were also weaker than those of Brown and co-workers (2016) (4.0%), however the backs of this study were stronger (-2.9%).

Comparison of peak torque angle of knee extension and flexion with Brown and colleagues (2014) revealed the forwards of this study performed at smaller and larger angles (-8.5% and 20.2%, respectively), while backs of this study performed at smaller angles (-6.1% and

-7.7%, respectively) than their rugby union counterparts. Notably, forwards in the current study showed a tendency to achieve peak torque at greater angles indicating their optimal muscle length was longer than backs in this study. Contextually, forwards routinely execute actions from crouched positions (i.e. flexed hip with large knee angles) such as in ruck clearing, scrummaging and mauling, which could explain this observation (Deutsch, Kearney, & Rehrer, 2007; Quarrie & Wilson, 2000). However, these findings must be considered with caution as the variation of training styles among participants has been shown to influence isokinetic results (Brughelli, Cronin, & Nosaka, 2010). Though more research is needed in this area, this finding does not agree with previous reports of forwards performing isokinetic testing optimally at shorter muscle lengths compared to backs (Brown et al., 2016).

There are reports of statistically non-significant differences in isometric strength between sub-groups of football code athletes (Comfort et al., 2011), which is similar to the findings of the current study. Though the capacity to generate force has been associated with performance in COD tasks (Shillabeer et al., 2015; Spiteri et al., 2013; Spiteri et al., 2015; Suchomel et al., 2016), this contention was not supported by the findings which showed non-significant association between peak relative isometric force and performance. The lack of agreement between maximal isometric strength and performance in COD tasks may be attributed to the force-velocity relationship, with time duration as the limiting factor (Suchomel et al., 2016; Winter et al., 2016). The duration of propulsive force production, and the rate at which it is developed during sprint-steps (e.g. approach and exit sprints) and the COD-step occur over shorter time intervals when compared to that of the maximal isometric testing. The force produced during maximal isometric testing occurred over a longer time interval at zero velocity, thus affording higher magnitudes (Suchomel et al., 2016; Winter et al., 2016). Thus task-specific differences in muscle mechanics may have contributed to the lack of agreement. It has been proposed the shorter time intervals to exert force during foot contacts in athletic manoeuvres at speed may make measures like RFD more appropriate for monitoring performance as they share more similar characteristics to rapid athletic tasks (Suchomel et al., 2016). This contention is supported by the RFD over ascending time intervals being correlated to performance in a 180-degree COD task (Wang et al., 2016). Differences in methodology, sample size and sampled populations may also be contributors.

Jump displacement is a popular performance measure among coaches and sports scientists due to their high validity, reliability and practicality. In the current study, relative jump displacement was excluded from analysis due to most successful outcomes in football codes being predicated on absolute jump distances. Apart from a trivial difference in right-leg horizontal DJ (ES = -0.10), backs outperformed forwards in unilateral jumping tasks. This was expected due to the positional responsibilities of backs generally involving the expression of unipedal speed-strength (e.g. sprinting and tackling at speed) (Deutsch et al., 2007). Unexpected was unilateral vertical jump height being the only displacement that definitively demonstrated categorical differences. Also unexpected was left- and right-leg vertical CMJ (ES = 1.47 and 1.36, respectively) showing greater categorical differences than vertical DJ (ES = 0.89 and 0.66, respectively). There are limited reports examining multidirectional unilateral jump performance in football code forwards and backs.

An interesting finding of this study was vertical plane impulse and take-off velocity during unilateral jumping having the most observations of significant large to very large association (22 total correlations) with COD times. The greater association between vertical impulse and take-off velocity and COD times can be readily explained by Newton's second law of motion; more specifically the impulse-momentum relationship (Winter et al., 2016). Irrespective of jump goal, the mechanical determinants for achieving the jump goal are impulse and take-off velocity in the vertical plane (Kakihana & Suzuki, 2001). Therefore, the association with COD times was expected. Reports have demonstrated larger magnitudes of vertical force are exerted when compared to that of horizontal force in a 180-degree COD tasks (Barnes et al., 2007; Dos'Santos et al., 2017). Recently vertical force-time measures have been shown to distinguish faster and slower performances in 180-degree and multidirectional COD tasks (Spiteri et al., 2015). Unexpected was the lack of relationship jump distances had with COD times due to previous reports of favourable correlation between CMJ and DJ jump distances and COD times (Castillo-Rodríguez et al., 2012; Lockie, Callaghan, et al., 2014; Lockie, Schultz, et al., 2014; Meylan et al., 2009). Differences in COD tasks employed may have contributed to the lack of agreement. The COD tasks used previously consisted of multiple successive directional changes, whereas the current study consisted of one direction change at speed.

Another interesting finding was the specific association CMJ and DJ mechanical measures had with approach, exit and total COD times. When all jump-COD correlations (45 total) were separated according to the associated task, CMJ measures associated more with approach and total times of both 180-degree and 45-degree COD tasks. Conversely, DJ measures associated more with exit times of 45-degree COD tasks. The specific association between CMJ and approach time is concurrent with previous reports of jumps that occur over a longer duration, such as SJ and CMJ, are more related to the acceleration phase in pure straight-line sprinting (Dobbs et al., 2015), and the acceleration in straight sprint paths about the COD-step (Los Arcos et al., 2017). The specific association CMJ measures have with total time may be explained by the proportionate increase in correlation CMJ performance had with straight-line sprint times as sprint distance increased (Dobbs et al., 2015; Vescovi & McGuigan, 2008). The mechanics expressed during the longer ground contact time of CMJ may also correspond more to the step kinetics over the approach phase and entire sprint path.

Given that cutting manoeuvres occur over a shorter time due to the smaller change in velocity, the specific association DJ mechanics have with the exit time of the 45-degree COD task was expected. Accentuated multidirectional jumping has been suggested as an appropriate training tool for enhancing performance in COD tasks due to emphasis of similar neuromuscular capabilities (Dobbs et al., 2015; Holm et al., 2008; Marshall et al., 2014). The current findings support this recommendation as the vertical, anterior-posterior and medial-lateral force-time variables of single-leg multidirectional DJ shared large correlation with the exit time of the 45-degree COD task.

Interestingly, peak and mean eccentric and concentric force, and eccentric time of the vertical DJ only correlated with exit time of the 45-degree COD task. Recently, significant association has been found between vertical and horizontal force production (Condello et al., 2016). Athletic manoeuvres executed in the horizontal plane have also been reported to exhibit higher magnitudes of vertical force than horizontal force (Dos'Santos et al., 2017; Kakihana & Suzuki, 2001; Loturco et al., 2015; Spiteri et al., 2013). It is also proposed vertically-oriented jumping tasks may serve as diagnostic tools in addition to their horizontally-oriented counterparts. These contentions are supported by the moderate and large differences between forwards and backs in vertical CMJ and DJ, and lack thereof in

horizontal CMJ and DJ. Forwards performing better in vertical CMJ may be attributed to their ability to overcome inertia over longer time periods, much like many of their positional responsibilities (e.g. scrummaging and receiving a line-out) (Deutsch et al., 2007; Quarrie & Wilson, 2000). Conversely, backs performing better in vertical DJ may be attributed to their ability to overcome inertia over shorter time intervals, much like many of their positional responsibilities (e.g. high velocity sprinting and tackling at speed) (Deutsch et al., 2007). Nonetheless more research in this area is needed.

Practical Applications

The association CMJ and DJ impulse and take-off velocity had with 180-degree and 45-degree COD performance suggests practitioners emphasise the orientation (direction) and the time duration of exerted force during jump training. This mechanical emphasis during jump training can have a positive influence on performance in COD tasks that require large and more modest changes in velocity. The specific association multidirectional CMJ and DJ kinetic variables had with tasks within each 180-degree and 45-degree COD test suggests CMJ training will benefit performance in pre-COD-step tasks (e.g. approach phase) and overall performance (total time) regardless of the magnitude of velocity change. Conversely, DJ training will benefit post-COD-step tasks in more rapid COD events such as sidestepping to evade a tackler. Speed-strength measures were superior in distinguishing forwards and backs, and superior in association to performance in 180-degree and 45-degree COD tasks. Also, it appears jump training in the vertical plane alone may be sufficient in enhancing performance in COD tasks that require large and more modest velocity changes. This would be practically beneficial in settings with limited training and testing time. Lastly, COD tasks that necessitate higher speeds and less direction change may offer better tests that distinguish differences among football code athletes. It should be noted that these findings may be specific to the cohort in this study. Therefore, it is recommended that practitioners examine all measures of this study within the athletes they are to train.

Chapter 6 – Effects of a Six-week Strength Training Programme on Change of Direction Performance in Youth Rugby Athletes

This chapter comprises the following publication in *Sports*.

Reference:

Bourgeois FA, Gamble PG, Gill ND, McGuigan MR. Effects of a six-week strength training programme on change of direction performance in youth team sport athletes. *Sports* 5(4): 83-100, 2017.

Author contribution:

Bourgeois FA, 85%; Gamble P, 5%, Gill ND, 5%; McGuigan MR, 5%.

Overview

In Chapter 2 the rationale for examining the influence eccentric strength training has on COD capabilities was established. In Chapter 5 statistical association between peak and mean eccentric measures during vertical DJ and 45-degree COD performance in football code athletes provided justification for investigating the influence eccentric strength training would have on 180-degree and 45-degree COD performance. The primary aim of this study was to investigate the effects 6 weeks of eccentric strength training had on unilateral force production and 180-degree and 45-degree COD performance in youth rugby union players. Secondly, category- and task-specific changes in performance measures were explored. The practical significance was providing insight into time-dependent training responses of unilateral strength and COD capabilities following a more practical eccentric strength training mode, which can be used to guide training.

Introduction

The importance of strength or force generating capacity for various athletic tasks is well documented, and these benefits concern both injury risk and sport performance (Baker, 2002; Gamble, 2011; Haff & Nimphius, 2012; Nimphius et al., 2010; Speirs, Bennett, Finn, & Turner, 2016; Suchomel et al., 2016). Force generating capacity is required any time the athlete must overcome inertia, and this concerns both 'deceleration' and acceleration (Barnes et al., 2007; Schot et al., 1995; Spiteri et al., 2013; Spiteri et al., 2015; Suzuki et al., 2014). During competition team-sport athletes are frequently required to change the velocity of their centre of mass, such as when responding to the movement of an opponent or ball (Gamble, 2011). Developing force-generating capacity relative to body mass can therefore be considered critical in improving these capabilities for team-sport athletes (Baker & Newton, 2008; Comfort, Haigh, & Matthews, 2012; Gabbett & Seibold, 2013).

Several investigations have reported the association between strength measures, such as 1-repetition maximum (1-RM), and performance in various COD assessments (Jones et al., 2009; Spiteri et al., 2015; Spiteri et al., 2014; Watts, 2015). Accordingly, recent studies have demonstrated strength training to be effective in enhancing performance in COD tasks (de Hoyo et al., 2015; Keiner et al., 2014; Speirs et al., 2016). Equally, there are reports of trivial associations between strength measures and performance in COD tasks (Chaouachi et al., 2009; Hojka et al., 2016; Markovic, 2007) (Chapter 5). These equivocal findings regarding COD have recently raised questions concerning the current structure (i.e. suspected contributing factors) of the deterministic model (Hojka et al., 2016). Furthermore the disagreement in the literature, and reports of several muscle qualities being associated with performance in COD tasks (Spiteri et al., 2014) highlights the need to investigate the influence training specific muscle strength qualities has on COD capabilities in various athletic populations.

Eccentric training modalities have received considerable research interest as a potential means that facilitates substantial increases in force-generating capacity (de Hoyo et al., 2015; de Hoyo et al., 2016). Preliminary evidence also suggests this form of training is effective in eliciting changes in plant-step kinetics of COD tasks, thereby benefiting performance (de Hoyo et al., 2015; de Hoyo et al., 2016). To date investigations employing eccentric strength interventions have employed specialised equipment to administer

eccentric overload in the form of additional resistance during the eccentric phase (de Hoyo et al., 2015; de Hoyo et al., 2016). However, these methods may not be feasible in all training environments due to facility restrictions and a lack of such specialised equipment. Another method of providing added emphasis on the eccentric phase is to constrain the manner in which the exercise is performed by extending the duration of eccentric activity.

Different COD tasks performed under distinct conditions involve unique mechanical constraints (Schot et al., 1995; Spiteri et al., 2015). Therefore, the kinetics of the tasks differ according to the magnitude of change in *velocity* – i.e. both direction and approach speed. For instance, performance outcomes in relation to tasks that require large and more modest angles of direction change, for instance 180-degrees versus 45-degrees, require different relative eccentric and concentric demands. What implications this has in relation to strength development is yet to be established in the research literature.

The present investigation examined the effects of an eccentric phase-emphasis isoinertial strength training (EPE) intervention on maximal force production in adolescent rugby union athletes. In turn the objective was to compare the effects of strength gains elicited via EPE and conventional training (CON) on performance in COD assessments requiring large (180-degrees) and more modest (45-degree) direction changes. Also examined were differential effects of strength changes between sub-groups categorised as 'fast' (FAST) and 'slow' (SLOW) determined via baseline COD trial times.

It was hypothesised EPE would enhance strength to a greater degree than CON. Also hypothesised was gains in strength elicited via EPE would be reflected in greater improved performance in the COD tasks employed. It was further hypothesised that EPE would facilitate a greater relative improvement in performance in the 180-degree COD task. Performance changes were noted seven weeks and ten weeks (3-week cessation) following the completion of each training intervention to capture the delayed training effects associated with each training modality.

Methods

Experimental approach to the problem

A 12-week one-group time-series design was used to monitor training responses to EPE and CON with respect to time (Figure 6.1). The following training schedule was used (*n* = 12): pretest (week 0), 16 sessions of upper- and lower-body EPE resistance training, $posttest_1$ (week 7), 2 weeks of rest, $posttest_2$ (week 10), followed by a 3-week washout period.

Next, six athletes who completed EPE volunteered to complete strength training in a conventional manner, where the tempo of exercise (specifically eccentric durations) were self-selected. The training schedule of CON was as follows (*n* = 6): pretest (week 14), 17 sessions of upper- and lower-body CON resistance training, $posttest_1$ (week 21), 2 weeks of rest, and finally $posttest_2$ (week 24). Training responses to CON were noted, and then compared with that of EPE. All participants were familiarised in all tests and exercises during six 1-hour sessions prior to EPE pretesting. All participants were instructed to refrain from unusual or vigorous resistance exercise and cardiovascular activity (e.g. 1-RM or YoYo testing) during periods of rest, and not include any movements that were identical to any assessment encountered during testing.

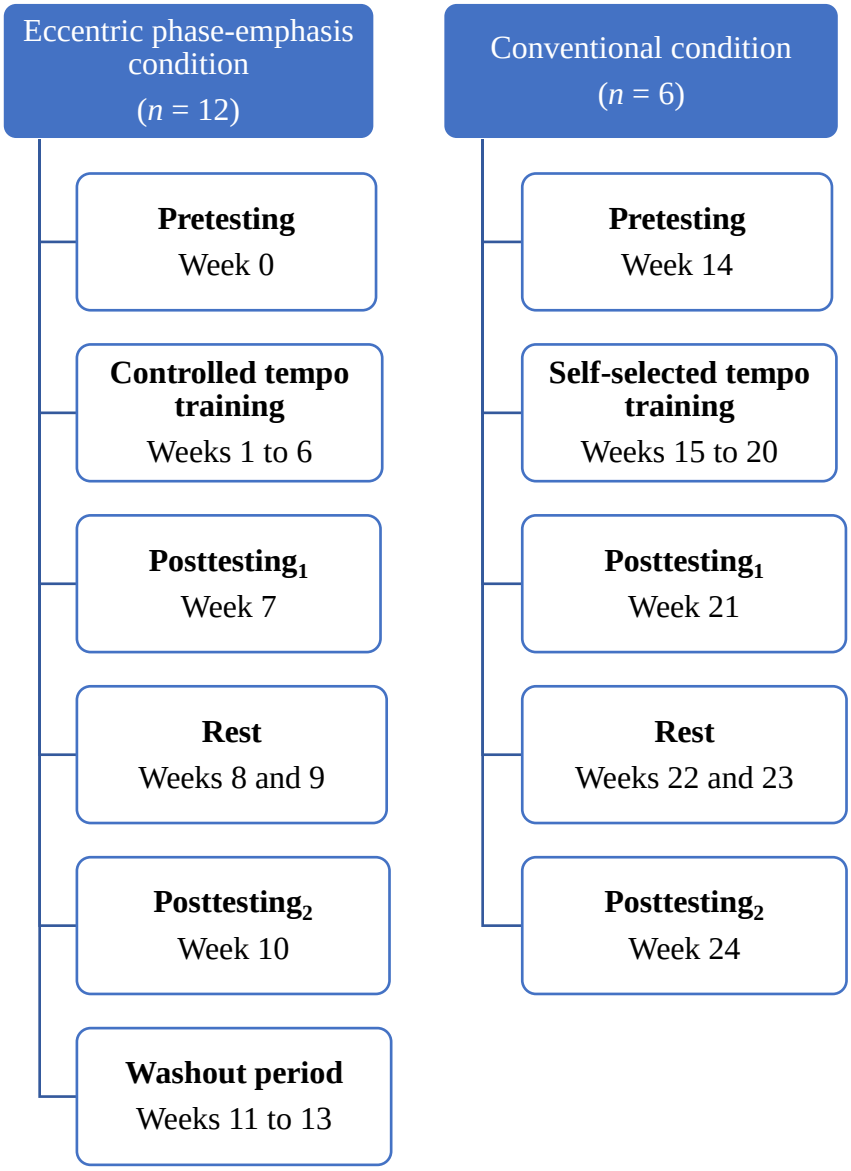

Figure 6.1. Testing and training schedules for eccentric phase-emphasis and conventional conditions.

Subjects

A total of 16 high school-aged rugby union athletes were recruited for the study. All participants were required to have at least six months of organised resistance training experience. Due to the potential of maturation factors contributing to variability within this cohort, peak height velocity was also assessed. A minimum completion of 13 out of the 16 training sessions (81.3%) was also required for inclusion.

Twelve participants (chronological age 15.0 ± 0.9 yr, height 1.8 ± 0.1 m, mass 80.2 ± 15.3 kg) successfully completed all testing and intervention for EPE. Following testing at the first 9-week mark, six participants dropped out due to other commitments and opportunities (e.g. promotion to the 1st XV squad). Six athletes from the EPE cohort (chronological age: 15.3 ± 0.5 yr; height: 1.8 ± 0.1 m; mass: 81.8 ± 12.4 kg) remained and were trained using CON.

All athletes and parents received an explanation of the study including detailed information concerning the risks and benefits. Written consent was obtained from both participant and parent before the study began. All procedures for this study were approved by Auckland University of Technology Ethics Committee (15/322).

Procedures

Anthropometrics

Body mass was measured to the nearest 0.01 kg using an electronic scale (Tanita, HD-351 Digital Weight Scale, Tokyo, Japan). Both standing and seated height were recorded to the nearest 0.01 m using a calibrated stadiometer (Height Stature Meter Retractable Measuring Tape, SKU TV121501, China). Two measurements were taken for each measure to ensure reliability (Mirwald et al., 2002).

The age of peak height velocity (APHV) and years from APHV were derived from date of birth, stranding height and seated height measurements using a web-based calculator developed by the Saskatchewan Childhood Growth and Development Research Group (Saskatoon, Saskatchewan, Canada) [assessed 25 July 2016]. These measures of maturation

were used to account for the relative stages of biological development among participants. Analysis of maturity status was deemed necessary due to the potential influence on performance in athletic tasks within adolescent athletes (Condello et al., 2013; Sherar, Mirwald, Baxter-Jones, & Thomis, 2005).

Change of direction assessment

Both 180-degree and 45-degree COD tasks were selected to evaluate performance in tasks that required relatively large versus more modest angles of direction change (Figure 3.2). Timing gates (Speed Light V2 gate, Swift, Wacol, QLD, Australia) were used to measure the sprint times of 180-degree and 45-degree COD tasks. To eliminate the influence of reaction time, participants began each trial at their own volition. Following three maximal effort familiarisation attempts, two trials were given and used for analysis. In a randomised order, separate trials were performed for each COD task, executing left- and right-leg plant steps, with two min rest between each trial. The contact zone for all attempts was marked with tape for consistency in foot placement during the plant-step. Pilot testing informed the location of the contact zones for respective COD assessments. Trials were deemed successful when the following criteria were fulfilled: maximum effort throughout the trial, participant remained within the designated 1.20 m perimeter; and plant-step placement within the designated contact zone.

A modified 505 was used to measure 180-degree COD performance (Nimphius et al., 2010). This assessment was selected based upon previous investigations demonstrating value in this COD task in relation to contact team sports (Gabbett, 2009). Most importantly, this test served as the COD manoeuvre that required a larger magnitude of direction change (i.e. 180-degree angle change). Participants began 0.30 m behind the start line in a staggered stance with the non-plant limb as the lead leg. Next, participants sprinted forwards, then executed a 180-degree turn in the 0.15 m × 0.60 m contact zone, before sprinting back in the opposite direction through the start/finish line.

The second COD assessment was a 45-degree cutting task. This test also served as a COD measure that is more specific to attacking manoeuvres in team sports (Spiteri et al., 2013). Most importantly, this test served as the COD task that required a more modest direction change (i.e. 45-degree angle change). As with the 180-degree task the participant began in a

staggered stance. When ready participants sprinted forwards, executed a 45-degree direction change (placing the respective foot within the 0.30 m × 0.60 m contact zone), then sprinted through the finish gate. A goniometer and tape were used to mark the sprint path after the plant-step. Variables of interest for both COD assessments were approach sprint time (i.e. sprint time prior to the plant-step), exit sprint time (i.e. sprint time after the plant-step) and total sprint time.

Strength assessment

Maximal unilateral lower-body strength was assessed via isometric mid-thigh pull in a traditional squat rack (McGuigan & Winchester, 2008). Two embedded 0.37 m x 0.37 m PASCO force plates (PS-2142, PASPORT 2-Axis Force Platform, CA, USA) were used to collect time series force data at a sampling rate of 200 Hz. Analog signals were amplified and converted with a two-channel 550 Universal Interface (UI-5001, PASCO Scientific, CA, USA). A custom-designed PASCO Capstone script (UI-5400, PASCO Scientific, CA, USA) was used to apply a moving average filter to data sets before reduction and extraction.

A handheld goniometer was used to adjust right knee and hip angles to 140- and 125-degrees, respectively (Comfort, Jones, McMahon, & Newton, 2015). Participants were instructed to place their left and right foot over the centre of the respective force plate and pull on an immovable bar (secured in a squat rack with pins) “hard and fast” for five seconds (McGuigan & Winchester, 2008). Following two submaximal 3-second repetitions, two 5-second maximal effort trials were given with three min rest between trials. Individuals began a test trial after the researcher gave a 3-second countdown. The variable of interest was normalised unilateral peak force.

Training protocol

Participants completed three training sessions weekly, lasting one hour per session, in addition to three 2-hour rugby practices. The EPE condition required the execution of upper- and lower-body isoinertial resistance exercise with controlled, 3-second eccentric (i.e. lengthening) durations, followed by concentric action performed as “fast as possible” in a safe manner. The duration of the eccentric phase was verified via video recording. The

time under eccentric tension (TUT) was defined as the time downward motion was initiated to the time downward motion ceased.

During CON the same exercises, sets and repetitions were employed in a conventional manner – i.e. with no constraints on tempo. Participants were therefore allowed to perform eccentric and concentric phases of each lift at self-selected velocities. As a result of the constraints for respective conditions, the resistances the participants could handle were markedly different (see Results).

Details of the exercises and repetition scheme are shown in Table 6.1. Main exercises were completed first followed by auxiliary exercises. Also, a 1:2 push to pull ratio was employed, with upper- and lower-body regions targeted in each session. It should be noted, some exercises, such as backward lunge and rear-elevated spilt squat were included to adhere to the pre-existing programming of the S&C coach and increase the ecological validity within this population. Loads lifted during training sessions were determined by individual ability, with weight selection guided by the execution of proper technique. Load, defined as the amount of mass lifted each set, was increased in the subsequent session if the athlete completed the respective lift correctly. Training volume (load × sets × repetitions) represented by arbitrary units (AU) was used to quantify training (Wernbom, Augustsson, & Thomee, 2007). To detect differences between EPE and CON conditions, lower-body, upper-body and total training volumes were calculated. Additionally, the session rating of perceived exertion (sRPE) was used as a subjective measure of training load (McGuigan & Foster, 2004; Singh, Foster, Tod, & McGuigan, 2007). Briefly, ten minutes after each training session athletes were asked to rate how hard their session was using the modified Borg category ratio scale (McGuigan & Foster, 2004). The RPE score was then multiplied by the total minutes of the training session (40 minutes) to calculate sRPE represented by AU (Singh et al., 2007).

Table 6.1. Exercises and repetition scheme administered during eccentric phase-emphasis and conventional conditions.

Targeted Body Region	Main Exercises	Auxiliary Exercises
Lower body exercises	Parallel back squat	Front squat
	Hexagon-bar squat	Front-racked backward lunge
		Rear elevated split squat
		Kettlebell lateral lunge
		Stiff-legged deadlift
Upper body exercises	Flat bench press	Dumbbell incline bench press
	Standing overhead press	Barbell pullover
		Unilateral dumbbell bench press
		Barbell inverted row
		Bent-over row
		Barbell upright row
		Prone kettlebell rows
		Dumbbell shoulder complex

Main exercises	Sets	Repetitions
Week 1	3	8, 10
Week 2	-	-
Week 3	-	6
Week 4	-	8, 10
Week 5	-	-
Week 6	-	6, 8

Assistant exercises	Sets	Repetitions
Week 1	3	5–8
Week 2	-	-
Week 3	-	6, 8
Week 4	-	6, 8, 10
Week 5	-	-
Week 6	-	4, 5, 8, 10

To verify the difference between EPE and CON, the duration of each lower-body eccentric action during both conditions was captured at 120 frames·s^{-1} using a high-speed video camera (Casio, Exilim EX-FH20, Tokyo, Japan). Video was analysed using kinematic analysis software (Kinovea, version 0.8.15).

The training protocol was scheduled on Mondays, Wednesdays and Fridays, and was additional to rugby practice (technical/tactical sessions) and conditioning sessions on Tuesdays and Thursdays. Also, this study began during the off-season (i.e. general preparation phase) and concluded during the in-season. Any additional activity performed by participants during both EPE and CON conditions (e.g. extra practices or games) were recorded, noting type of activity and duration.

Statistical Analysis

Means ± SD were calculated to represent the centrality and spread of data. Confidence limits were set at 90% (90%CL). Values for 90% CL were calculated by multiplying the standard error of the mean by the respective *t*-distribution probability value, then adding and subtracting that result from the respective group mean. All strength data were normalised to body weight (N). All variables were log transformed to reduce non-uniformity of error (Hopkins, 2000) with the mean of each variable used for analysis. The group median of total sprint times (calculated from the before-intervention data set) was used to segregate faster (FAST) and slower (SLOW) individuals to examine category differences (Hewit et al., 2013). Performance changes from pretest to $posttest_1$, $posttest_1$ to $posttest_2$, and pretest to $posttest_2$ were defined as T0, T1 and T2, respectively. Twelve and six individuals were analysed for EPE and CON responses, respectively. It should also be noted that the six individuals examined following CON were six of the 12 individuals examined following EPE.

Within-individual smallest worthwhile change (SWC) was determined via the comparison of individual percent change in mean and the coefficient of variation (CV, typical error relative to the group mean·100). A SWC was noted if the percent change was greater than the average CV of score one and score two. Typical error was calculated by dividing the SD of the difference scores by the square root of two (Hopkins, 2000). Additionally, individual changes in performance were quantified by the standardised differences (effect

size, ES) of both within and between EPE and CON conditions. Hedge's *g* effect sizes were calculated to adjust for the small sample size according to Ialongo (2016). Effect size thresholds of 0.20, 0.60, 1.20, 2.0 and 4.0 were used for small, moderate, large, very large, and extremely large, respectively (Hopkins et al., 2009).

Results

Maturation during the study

Estimated ages of FAST were: chronological age = 15.3 ± 0.6; peak height velocity = 13.9 ± 0.8; years from age of peak height velocity = 1.3 ± 0.7. Respective ages of SLOW were: 15.7 ± 0.6; 13.3 ± 0.4; 1.4 ± 1.3. Body mass, standing height and seated height changes between EPE and CON ranged from trivial to small (FAST ES: mass = 0.22; standing height = 0.05; seated height = 0.34; SLOW ES: mass = 0.20; standing height = 0.06; seated height = 0.23).

Observed differences between eccentric phase-emphasis and conventional training

Time under eccentric tension differences

Observations of EPE (*n* = 2042) and CON (*n* = 2279) training sessions revealed an extremely large difference (3.0 ± 0.2 s vs. 1.2 ± 0.2 s, ES = -7.67) in average time under eccentric tension when conditions were compared.

Training volume changes

The transition from EPE to CON showed FAST had a moderate decrease (91,832.0 ± 2025.0 AU vs. 89,581.0 ± 2193.9 AU, ES = -1.07) in lower-body training volume, while SLOW showed an extremely large decrease (95,298.0 ± 109.1 AU vs. 88,412.0 ± 3035.2 AU, ES = -4.38). Upper-body training volume showed FAST experienced a very large increase (58,152.0 ± 1065.5 AU vs. 62,701.0 ± 2742.4 AU, ES = 2.39), while SLOW showed a trivial increase (56,910.0 ± 540.5 AU vs. 56,993.0 ± 2186.0 AU, ES = 0.06).

Total training volume showed FAST experienced a moderate increase (148,604.0 ± 1453.6 AU vs. 151,298.0 ± 5092.7 AU, ES = 0.82), while SLOW showed a very large decrease (149,988.0 ± 540.8 AU vs. 145,383.0 ± 3733.3 AU, ES = -2.15).

Session-rating of perceived exertion changes

Within-group comparison of EPE and CON showed a very large increase in average sRPE in FAST (244.8 ± 23.9 AU vs. 275.6 ± 5.6, ES = 2.08), and a large increase in SLOW average sRPE (214.5 ± 5.8 vs. 237.8 ± 19.8, ES = 1.82). Between-group comparisons of sRPE showed FAST perceived greater exertion during EPE (ES = -2.03) and CON (ES = -2.97).

Changes in other training volume

Total minutes of other resistance and conditioning training reported by participants (activity not related to the study) during each condition revealed a small decrease (ES = -0.32) in activity between EPE and CON (327.9 ± 119.8 min vs. 277.1 ± 194.3 min, respectively).

Training responses

Raw data for EPE and CON strength training conditions can be found in Tables 6.2 and 6.3, respectively.

Table 6.2. Raw data for performance measures of the eccentric phase-emphasis strength training condition (*n* = 12).

Performance Measures	Left Leg					
	Pretest		Posttest$_1$		Posttest$_2$	
	Fast	Slow	Fast	Slow	Fast	Slow
Isometric peak force (N/N)	1.67 ± 0.18	1.69 ± 0.30	1.68 ± 0.32	1.61 ± 0.20	2.00 ± 0.28	1.89 ± 0.26
180-degree approach time (s)	1.08 ± 0.06	1.12 ± 0.07	1.08 ± 0.03	1.12 ± 0.02	1.09 ± 0.04	1.13 ± 0.07
180-degree exit time (s)	1.08 ± 0.12	1.06 ± 0.07	1.12 ± 0.08	1.09 ± 0.07	1.07 ± 0.04	1.13 ± 0.06
180-degree total time (s)	3.00 ± 0.17	3.16 ± 0.17	2.95 ± 0.12	3.10 ± 0.13	2.92 ± 0.05	2.95 ± 0.19
45-degree approach time (s)	0.95 ± 0.04	0.98 ± 0.03	0.95 ± 0.06	1.03 ± 0.04	0.98 ± 0.06	1.00 ± 0.04
45-degree exit time (s)	0.66 ± 0.06	0.74 ± 0.02	0.72 ± 0.08	0.77 ± 0.03	0.66 ± 0.05	0.74 ± 0.03
45-degree total time (s)	1.61 ± 0.08	1.72 ± 0.01	1.67 ± 0.12	1.80 ± 0.04	1.64 ± 0.09	1.74 ± 0.06

Performance Measures	Right Leg					
	Pretest		Posttest$_1$		Posttest$_2$	
	Fast	Slow	Fast	Slow	Fast	Slow
Isometric peak force (N/N)	1.72 ± 0.18	1.79 ± 0.30	1.85 ± 0.29	1.67 ± 0.24	2.14 ± 0.25	2.13 ± 0.32
180-degree approach time (s)	1.09 ± 0.08	1.09 ± 0.02	1.08 ± 0.04	1.10 ± 0.04	1.09 ± 0.06	1.11 ± 0.02
180-degree exit time (s)	1.14 ± 0.14	1.04 ± 0.06	1.11 ± 0.08	1.11 ± 0.08	1.07 ± 0.04	1.10 ± 0.08
180-degree total time (s)	3.00 ± 0.18	3.16 ± 0.12	2.98 ± 0.08	3.01 ± 0.10	2.90 ± 0.08	2.99 ± 0.17
45-degree approach time (s)	0.91 ± 0.03	0.99 ± 0.03	0.96 ± 0.02	1.00 ± 0.06	0.95 ± 0.01	1.00 ± 0.04
45-degree exit time (s)	0.63 ± 0.03	0.70 ± 0.04	0.69 ± 0.06	0.73 ± 0.05	0.64 ± 0.02	0.73 ± 0.05
45-degree total time (s)	1.54 ± 0.04	1.70 ± 0.07	1.65 ± 0.07	1.74 ± 0.11	1.60 ± 0.01	1.73 ± 0.09

Table 6.3. Raw data for performance measures of the conventional strength training condition (n = 6).

Performance Measures	Left Leg					
	Pretest		Posttest$_1$		Posttest$_2$	
	Fast	Slow	Fast	Slow	Fast	Slow
Isometric peak force (N/N)	1.59 ± 0.09	1.81 ± 0.26	1.99 ± 0.24	1.71 ± 0.13	1.63 ± 0.20	1.83 ± 0.43
180-degree approach time (s)	1.17 ± 0.07	1.16 ± 0.06	1.13 ± 0.02	1.13 ± 0.07	1.11 ± 0.03	1.10 ± 0.03
180-degree exit time (s)	1.07 ± 0.04	1.12 ± 0.10	1.09 ± 0.10	1.05 ± 0.06	1.12 ± 0.09	1.05 ± 0.06
180-degree total time (s)	2.94 ± 0.11	2.94 ± 0.16	3.00 ± 0.12	3.02 ± 0.19	2.95 ± 0.11	2.98 ± 0.19
45-degree approach time (s)	1.00 ± 0.02	1.00 ± 0.06	0.98 ± 0.03	0.99 ± 0.03	0.97 ± 0.05	1.10 ± 0.08
45-degree exit time (s)	0.77 ± 0.03	0.76 ± 0.11	0.79 ± 0.13	0.72 ± 0.07	0.73 ± 0.06	0.75 ± 0.17
45-degree total time (s)	1.69 ± 0.06	1.83 ± 0.10	1.65 ± 0.03	1.83 ± 0.06	1.62 ± 0.03	1.85 ± 0.17
Performance Measures	Right Leg					
	Pretest		Posttest$_1$		Posttest$_2$	
	Fast	Slow	Fast	Slow	Fast	Slow
Isometric peak force (N/N)	1.66 ± 0.24	1.50 ± 0.06	2.08 ± 0.36	1.95 ± 0.30	1.77 ± 0.34	1.78 ± 0.03
180-degree approach time (s)	1.09 ± 0.02	1.13 ± 0.04	1.12 ± 0.07	1.07 ± 0.07	1.13 ± 0.05	1.12 ± 0.02
180-degree exit time (s)	1.07 ± 0.07	1.14 ± 0.07	1.09 ± 0.04	1.04 ± 0.02	0.75 ± 0.03	0.74 ± 0.12
180-degree total time (s)	3.03 ± 0.15	2.90 ± 0.16	2.94 ± 0.06	2.98 ± 0.23	2.94 ± 0.04	2.94 ± 0.19
45-degree approach time (s)	0.99 ± 0.06	0.96 ± 0.03	1.02 ± 0.06	0.97 ± 0.06	1.13 ± 0.05	1.12 ± 0.02
45-degree exit time (s)	1.07 ± 0.07	1.14 ± 0.07	0.77 ± 0.05	0.65 ± 0.04	0.75 ± 0.03	0.74 ± 0.12
45-degree total time (s)	1.65 ± 0.13	1.71 ± 0.06	1.66 ± 0.09	1.82 ± 0.09	1.71 ± 0.14	1.76 ± 0.12

Relative peak isometric force production changes

Following EPE neither FAST nor SLOW improved at T0, indicating no changes in left- and right-leg strength were apparent between baseline and posttest$_1$ (ES = -0.56 to 0.46) (Figure 3). However, both FAST and SLOW recorded improvements in left- and right-leg strength at T1 (ES = 0.96 to 1.56) and T2 (ES = 0.66 to 1.77).

Following CON FAST improved in left- and right-leg strength at T0 (ES = 1.93 and 1.41, respectively), but showed no improvements at T1 and T2 (ES = -1.51 to 0.39) (Figure 3). Only SLOW showed improvements in right-leg strength at T0 and T2 (ES = 2.13 and 4.01, respectively).

Between-condition comparison revealed a greater relative benefit in left- and right-leg strength at T0 following CON (ES = -0.14 to 3.02). However, at T1 and T2 FAST and SLOW showed a greater relative improvement in left- and right-leg strength following EPE (ES = -1.78 to 0.75).

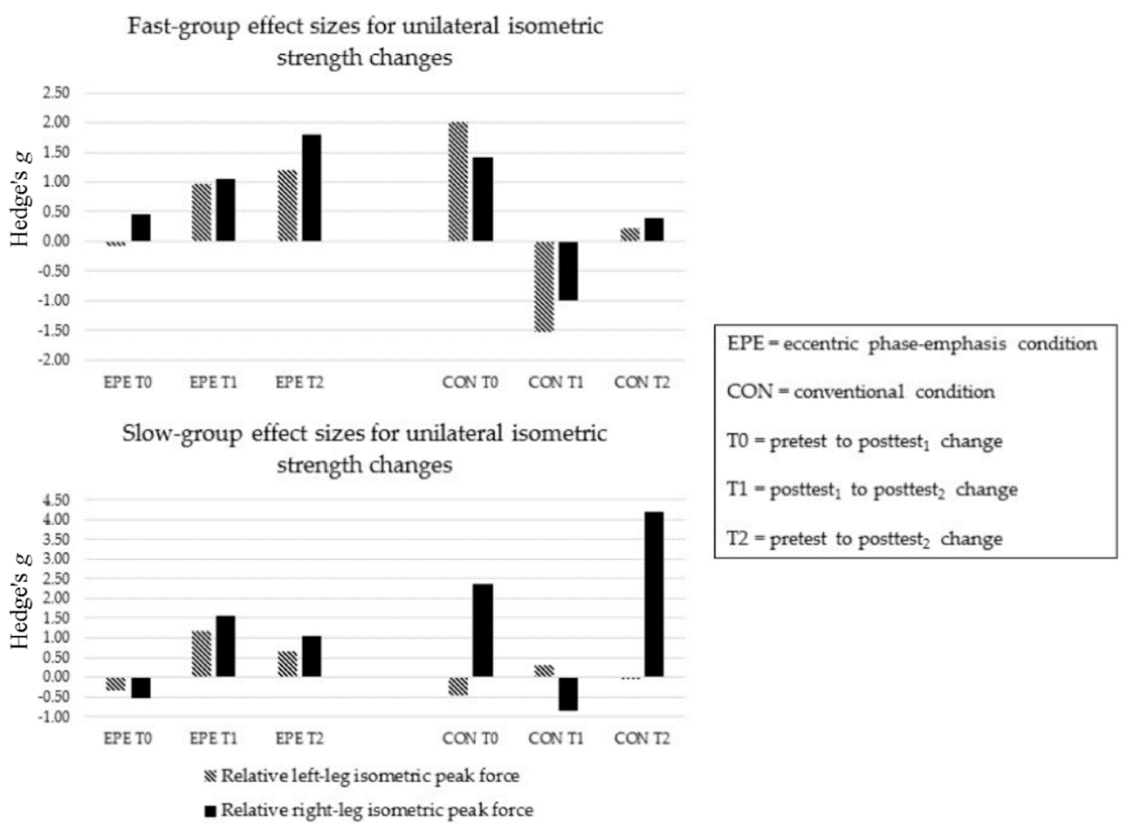

Figure 6.2. Sub-group unilateral isometric strength changes.

Change of direction performance

180-degree COD performance

During EPE neither FAST nor SLOW showed improvement in approach and exit time at T0, T1 and T2 (ES = -0.51 to 0.89). (Figure 6.3 and 6.4). FAST improved in left- and right-leg total time at T2 (ES = -0.23 and -0.85). SLOW improved in left-leg total time at T1 and T2 (ES = -0.92 and -1.13, respectively), and right-leg total time at T0 and T2 (ES = -1.31 and -1.22, respectively).

During CON FAST and SLOW improved in left-leg approach time at T2 (ES = -0.85 and -1.10, respectively) (Figure 6.3 and 6.4). Only SLOW improved in right-leg approach time at T1 (ES = -0.75). SLOW improved in left-leg exit time at T0 and T2 (-0.76 and -0.65, respectively). FAST improved in right-leg exit time at T1 and T2 (-7.70 and -4.39, respectively), while SLOW improved at T0, T1 and T2 (-1.26, -3.06 and -3.86, respectively). Neither FAST nor SLOW improved in left-leg total time (ES = -0.37 to 0.55). Only FAST improved in right-leg total time at T0 and T2 (-0.74 and -0.77, respectively).

Between-condition comparison revealed a minimal relative difference between conditions in left-leg approach time at all time-points (ES = -0.31 to 0.13). FAST showed a greater relative benefit in right-leg approach time following EPE (ES = 0.02 to 0.42), while SLOW showed a greater relative benefit following CON across all time-points (ES = -0.55 to 1.35). FAST showed a greater relative benefit for left-leg exit time at all time-points following EPE (ES = -0.13 to 1.06), while SLOW showed minimal difference between conditions (ES = -0.19 to 0.01). Both FAST and SLOW showed a greater relative benefit in right-leg exit time following CON (ES = -2.28 to 0.88). Lastly, both FAST and SLOW showed a greater relative improvement in left- and right-leg total time following EPE (ES = -0.23 to 0.73).

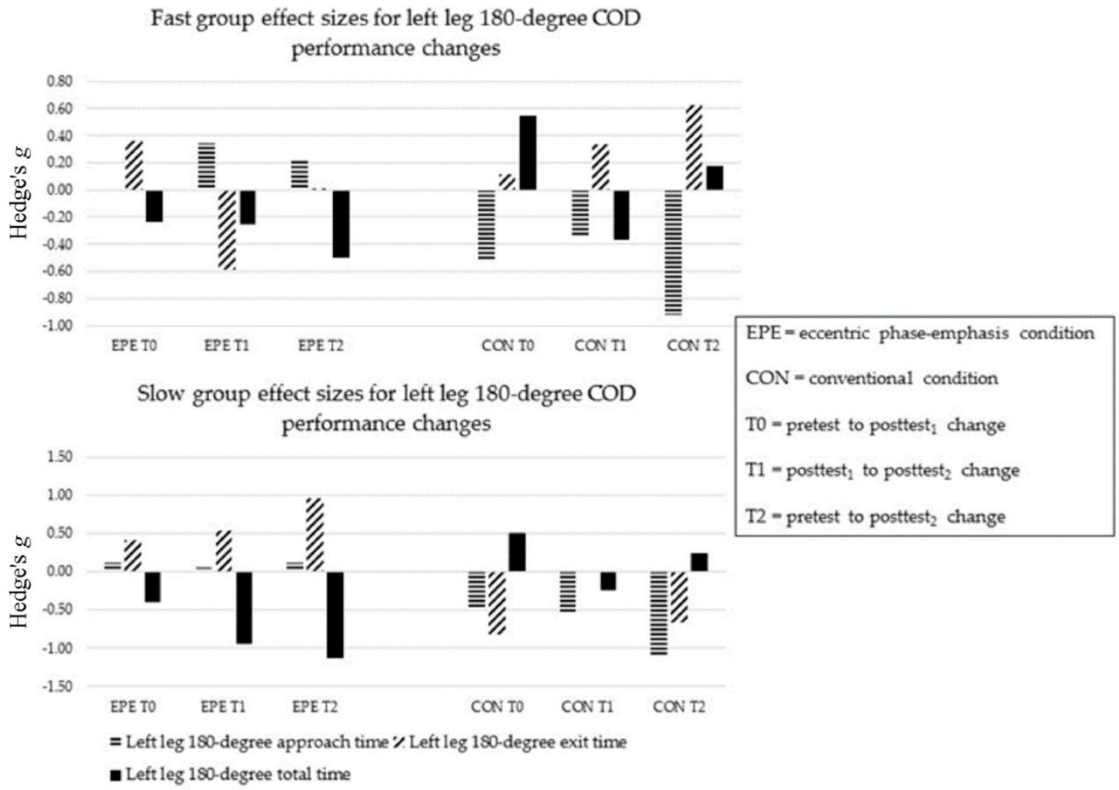

Figure 6.3. Sub-group left-leg 180-degree COD performance changes.

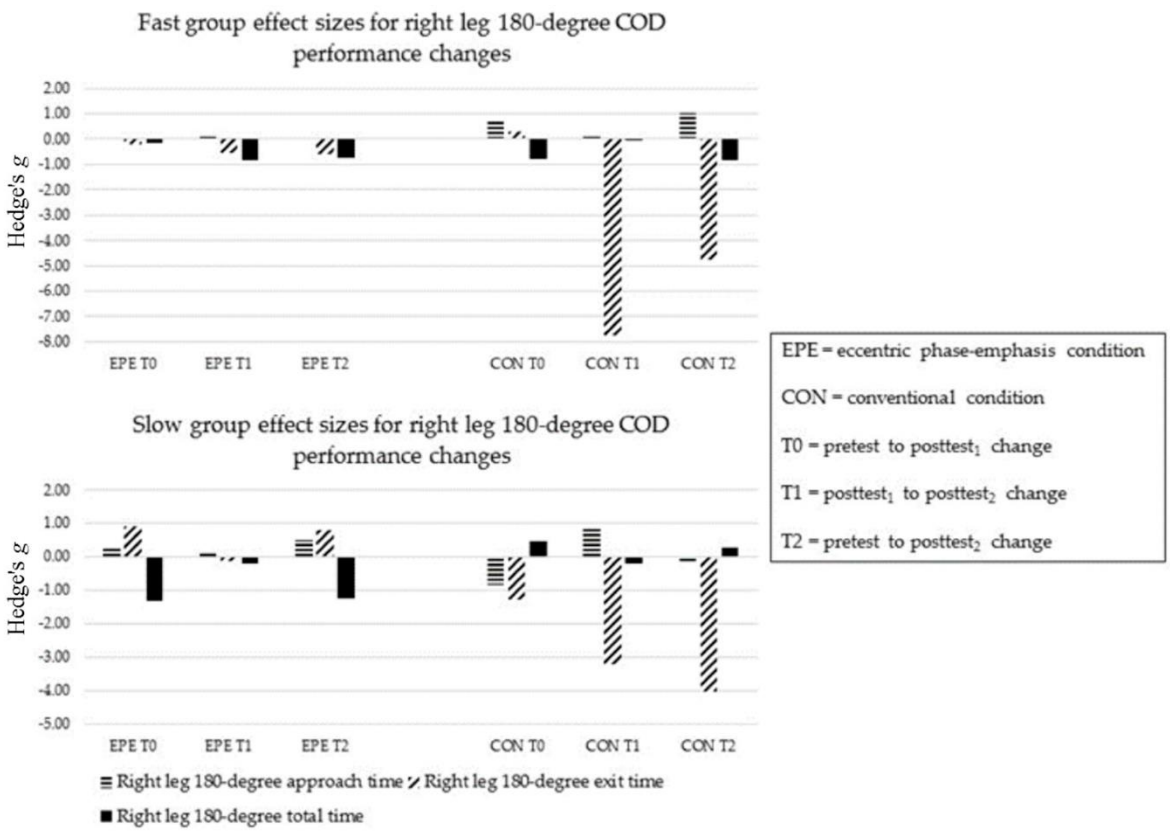

Figure 6.4. Sub-group right-leg 180-degree COD performance changes.

45-degree COD performance

Following EPE SLOW improved in left-leg approach time at T1 (ES = -0.84) (Figure 6.5 and 6.6). FAST improved in left- and right-leg exit time at T1 (ES = -0.87 and -0.81, respectively), while SLOW improved in left-leg exit time at T1 (ES = -0.91). SLOW improved in left-leg total time at T1 (ES = -1.19), while FAST improved in right-leg total time at T1 (ES = -0.83).

Following CON neither FAST nor SLOW improved in approach time (ES = -0.57 to 4.61) (Figure 6.5 and 6.6). FAST however improved in left-leg exit time at T2 (ES = -0.75). Both FAST and SLOW improved in right-leg exit time at T0 and T2 (ES = -7.84 to -3.65). Only FAST improved in left-leg total time at T1 and T2 (ES = -0.79 and -0.87, respectively).

Between-condition comparison revealed FAST and SLOW had minimal relative difference between conditions in left-leg approach time at all time-points (ES = -0.13 to 0.35). FAST and SLOW showed greater relative benefit in right-leg approach time following CON (ES

= -1.48 to 0.01). Except for SLOW at T1 (EPE, ES = 1.37), FAST and SLOW showed minimal relative difference between conditions in left-leg exit time (ES = -0.57 to 0.44). FAST showed a greater relative benefit in right-leg exit time following EPE at T0 and T2 (ES = -0.16 and 0.85, respectively), while SLOW showed greater improvement following CON (ES -5.19 to -0.80). FAST showed minimal relative difference between conditions in left-leg total time (ES = -0.30 to 0.00). At T0 SLOW showed a greater relative benefit in left-leg total time following CON (ES = -0.64), however showed greater benefit following EPE at T1 (ES = 0.70). FAST showed a greater relative benefit in right-leg total time following EPE at T2 (ES = -0.61). SLOW showed minimal relative difference between conditions in right-leg total time.

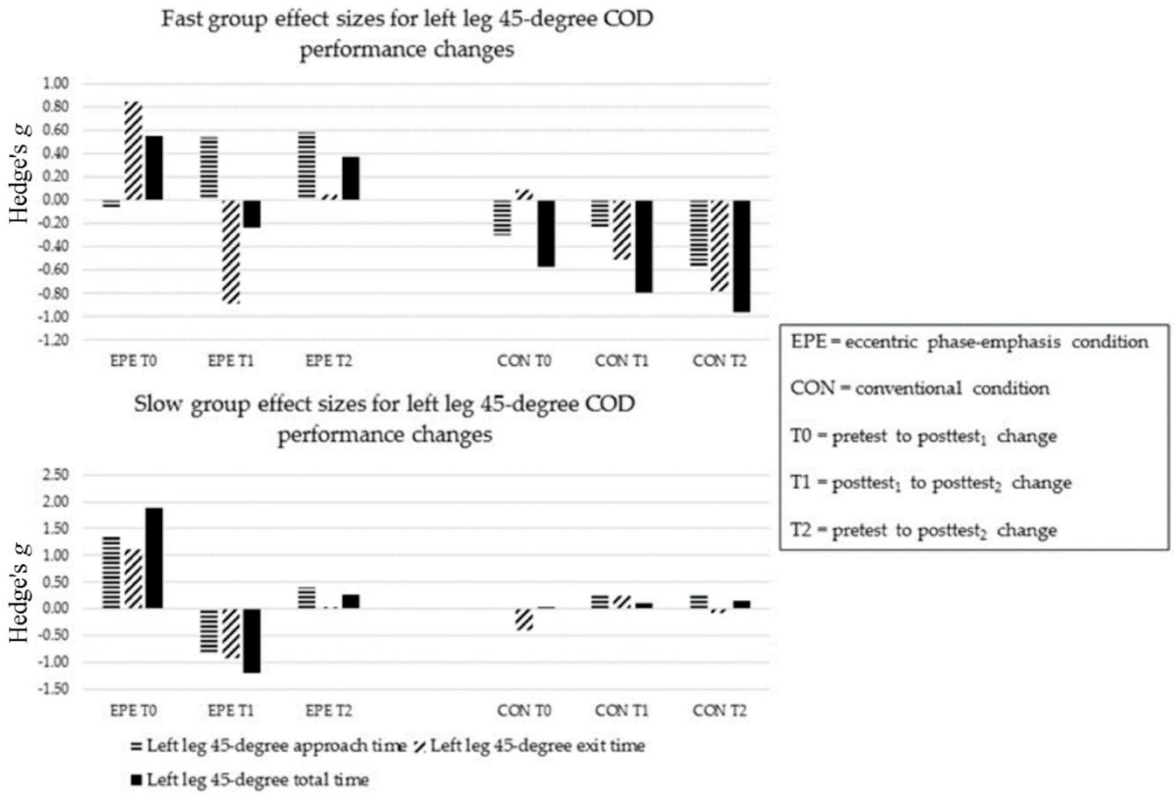

Figure 6.5. Sub-group left-leg 45-degree COD performance changes.

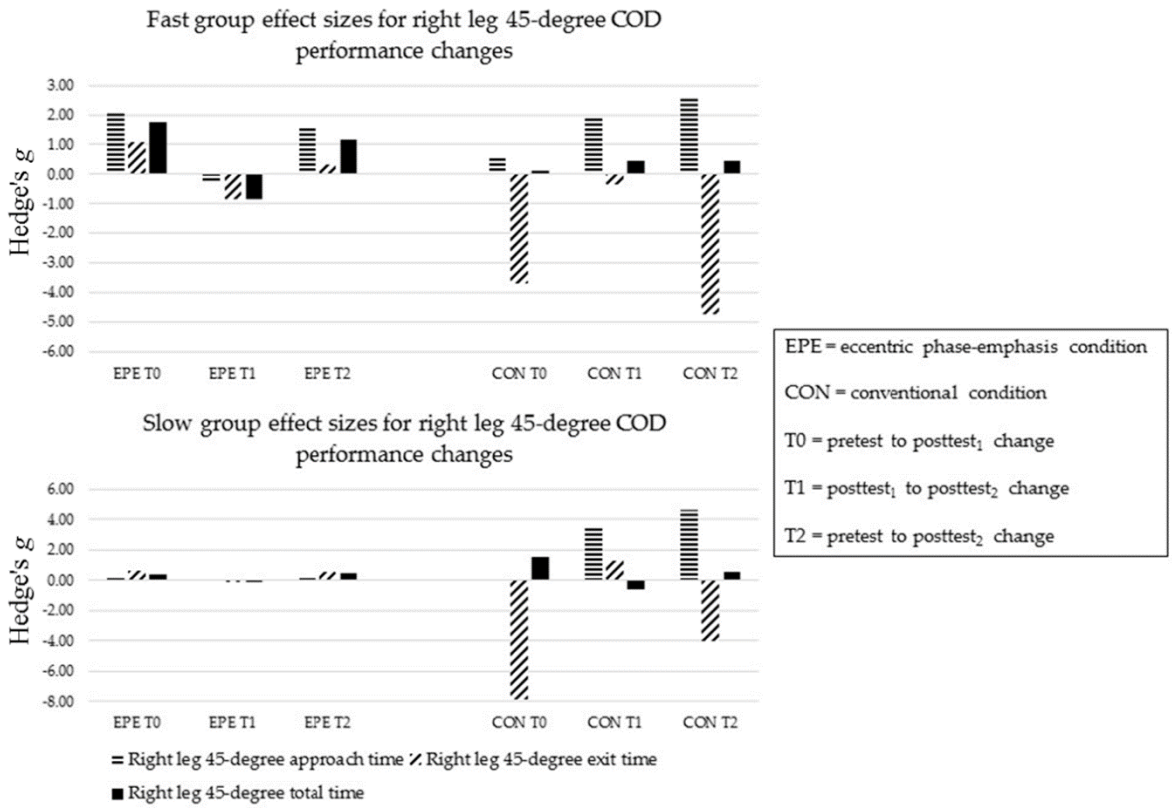

Figure 6.6. Sub-group right-leg 45-degree COD performance changes.

Discussion

The primary purpose of this investigation was to examine the effects of a free-weight eccentric phase-emphasis strength training intervention on maximal unilateral force production in adolescent rugby union athletes. The secondary purpose was to examine differential effects of strength changes among sub-groups of individuals rated as ‘fast’ and ‘slow’ assessed via baseline performance in COD measures prior to intervention. The final purpose was to examine the specific effects strength gains had with the respective COD assessments requiring large (180-degrees) and more modest (45-degree) direction changes.

There are several important findings of this study. The first was training responses were mode-specific (i.e. EPE vs. CON). Specifically, CON was more beneficial in facilitating more acute enhancements in unilateral isometric strength, while EPE was more beneficial retaining and further enhancing unilateral isometric strength. Next, training responses were task-specific (e.g. left-limb 180-degree COD total time vs. left-limb 45-degree COD total time). Specifically, CON was more beneficial for approach and exit times in both 180-degree and 45-degree COD tasks, while EPE was more beneficial for total time in 180-

degree COD tasks. Finally, specific effects in sub-groups (e.g. FAST vs. SLOW) were observed. That is, when responses in strength and COD measures were compared slower individuals benefited more from EPE, while their faster counterparts experienced meaningful improvements of lesser magnitudes. Also, when training volumes were compared faster individuals coped with EPE better than their slower counterparts.

Overall, EPE facilitated a greater improvement in unilateral isometric strength than CON. This finding agrees with previous research showing submaximal eccentric resistance training being efficacious in improving strength measures (de Hoyo et al., 2015; Douglas et al., 2017; Hortobágyi et al., 1996; Isner-Horobeti et al., 2013; Keiner et al., 2014). The prolonged stretch of activated muscle experienced during eccentric exercise has been shown to be a potent stimulus for facilitating favourable molecular and neuromuscular responses, such as enhancements in net protein turnover and unique central nervous system activation strategies (Douglas et al., 2017; Isner-Horobeti et al., 2013).

Interestingly, when condition-specific strength responses were compared relative to time, CON was initially more beneficial, and as time progressed EPE became more beneficial. There are investigations reporting the time-course of strength adaptation relative to training and detraining (Kubo, Ikebukuro, Yata, Tsunoda, & Kanehisa, 2010; Ogasawara, Yasuda, Ishii, & Abe, 2013; Secomb et al., 2015). Kubo and colleagues (2010) observed a small non-significant increase in unilateral isometric knee extension strength following one month of isometric training during the training phase. One month into the detraining phase a significant ($p < 0.001$) increase in unilateral strength was observed. Ogasawara and colleagues (2013) observed a significant ($p < 0.05$) decrease in specific strength (1-RM·muscle cross-sectional area^{-1}) following six weeks of dynamic strength training. Following a three-week cessation, a large non-significant increase in specific strength was observed. Isometric measures displayed a similar response (strength decrease followed by subsequent increase) yet were non-significant. The non-significant result may be attributed to the high variability (between-individual SD) within the measure. Recently, Secomb and co-workers (2015) investigated isometric strength response following a three-week cessation from dynamic strength training (14 sessions) in adolescents. Similar to the current study, there was no immediate statistical change in strength. However, following the three-

week cessation a significant increase (ES = 0.97, $p < 0.05$) was observed between pretest and post-cessation relative bilateral isometric strength.

The differential responses (i.e. EPE vs. CON) observed in this study could be due to the difference in time under eccentric tension (TUT) associated with each mode. The initial decline (T0) in isometric force production following EPE is likely a resultant of increased exercise-induced muscle damage from prolonged TUT (Douglas et al., 2017; Wernbom et al., 2007) associated with EPE. In the current study, long muscle lengths achieved during exercise coupled with the relatively low training age of the participants may have exacerbated exercise-induced muscle damage delaying the training effect at T1 (Baker, 2002; Douglas et al., 2017; Hortobágyi et al., 1996; Isner-Horobeti et al., 2013; Saxton & Donnelly, 1996).

Responses in lower-body strength to EPE and CON showed task-specific benefits. Task-specific relationships were more apparent when the criterion measure of performance (total time) was examined for both fast and slow sub-groups. This selective benefit highlights the impact COD assessment selection can have on performance outcome and subsequently training foci. The mechanical determinants of changing sprint direction have been shown to be highly specific to the requirements of the task (Schot et al., 1995; Spiteri et al., 2015). Recently, the execution of a 180-degree COD at full pace was shown to require greater weight-acceptance and propulsive forces than the execution of a COD task that is composed of 180-degree and 90-degree direction changes at full pace (Spiteri et al., 2015). This observation is supported in the current study by the selective benefit eccentric exercise had on 180-degree COD performance and the deleterious effect on 45-degree COD performance.

The deleterious effect CON had on 45-degree COD performance was unexpected. The more similar muscle actions experienced during conventional resistance training and the more rapid 45-degree COD were expected to manifest a more positive relationship due to the two activities sharing more similar movement characteristics (Gamble, 2011; Spiteri et al., 2013). Indeed, a more rapid training mode (e.g. higher velocity eccentric strength training or accentuated jump training) may be needed to improve performance in the 45-degree COD tasks (Brughelli et al., 2008; Sheppard et al., 2014; Suchomel et al., 2016; Watts, 2015).

Changes in approach times appear to be mode-specific. Specifically, approach times for the 180-degree COD tasks showed CON tended to benefit both fast and slow sub-groups across all six measures (50.0% and 83.3%, respectively). Interestingly, there were three out of 12 instances where both conditions were deleterious to both fast (two measures) and slow (one measure) sub-groups. Conversely, approach times for 45-degree COD tasks revealed a more individual-specific response. The fast sub-group benefitted more from CON regardless of task orientation (83.3% of measurements), while the performance in the slow sub-group was equivocal. The left-leg 45-degree COD task showed a bias towards EPE, while the right-leg counterpart showed a bias towards CON.

Finally, changes in exit times appear to be category-specific where the fast and slow sub-groups benefitted more from EPE and CON, respectively. Due to approach and exit times reflecting sprint or acceleration capabilities, CON was expected to be more beneficial for these measures (Gabbett et al., 2008; Hewit et al., 2013). Previous reports have demonstrated an association between force production and sprint speed over distances of 5 and 10 m (Comfort et al., 2012). Therefore, the observed increases in unilateral isometric strength could have facilitated a positive transfer to sprint performances about the plant-step.

Notably, the within-individual variability observed suggests a need to monitor individual performance rather than group performance in COD tasks. Though greater categorical trends were observed, individual-specific responses were frequently observed when the cohort was separated into sub-groups of fast and slow. For example, consider performance changes experienced in EPE left-leg 180-degree COD exit times of the slow sub-group. Following EPE the sub-group (n = 3) showed a trivial negative response (ES = 0.09) from pretest to $posttest_2$. However, closer inspection revealed two individuals experienced large negative responses, while one individual showed a moderate positive response. Solely analysing group data could disguise individual responses to intervention, lead to misdirected training foci and potentially decrease the chances of within-individual performance enhancement. The individual-specific response may be related to some individuals being able to better cope with the higher stresses associated with EPE in combination with sport-specific training (Baker, 2002; Wernbom et al., 2007). This would explain the marked decrease in training volume of the slow sub-group, and the preference

for shorter TUT during resistance training. Monitoring within-athlete performance has been previously recommended due to individual responses observed following training (Claudino et al., 2016; Claudino et al., 2013; Meylan et al., 2009). Similarly, the current findings suggest practitioners track within-individual strength and COD measures to more accurately address the more present needs of the athlete.

There are several limitations to the current study. First, the small sample size limits the statistical power and conclusions that can be drawn. It is also important to note that this is a unique athletic population (i.e. adolescent rugby union athletes). As such, it is not advised to generalise findings to other populations, differing in sex and maturation stage. Next, the relationships observed are only applicable to the COD tasks of this study, and should not be generalised to performance in all pre-planned tasks. It is also acknowledged that variability across measures may be a function of fatigue accumulated over 24 weeks. The small change in minutes of non-research related activity (ES = -0.32) during both conditions would suggest accumulated fatigue did not influence performance outcome within this cohort. However, closer inspection revealed both fast and slow sub-groups had very large and large within-group increases in sRPE from EPE to CON (ES = 2.08 and 1.82, respectively). Between-group sRPE revealed the FAST perceived greater exertion than the slow sub-group during EXP and CON (ES = -2.03 and -2.97, respectively). Greater sRPE accompanied by a higher training volume in the FAST would suggest the slow sub-group may have adjusted their behaviour (e.g. load selection) to cope with all encountered activities (Claudino et al., 2016; Hortobágyi et al., 1996; McGuigan & Foster, 2004). Finally, the high amount of variability in the approach and exit times of the current study makes group findings unclear. A possible contributing factor to the high variability observed is the increased variation innate to the selection and execution of entry and exit strategies (e.g. sprint paths and foot placement) in turning tasks at speed (Arshi et al., 2015; Bartlett et al., 2007; Davids, Button, Araujo, Renshaw, & Hristovski, 2006; Qiao et al., 2014). Nonetheless, the greater stability among total sprint times provided a relatively clear indication of specific training responses. These findings emphasise the selection of COD assessments associated with general and position-specific demands with primary attention given to total time to complete COD tasks be considered by practitioners. Practitioners are also advised to establish the mechanical determinants of COD tasks selected, and determine neuromuscular characteristics favourable to performance within the athletes to be trained.

Future research should examine the efficacy of eccentric phase-emphasis resistance training in athletic performance across sex, training age, sport and position. Additionally, longitudinal investigation of this training mode across these categories is warranted.

Practical Applications

Submaximal eccentric phase-emphasis resistance training is a practical method for introducing a potent stimulus for enhanced growth and function in a safe manner. Also, each training mode in the current study may offer additional strategies for effecting timely favourable performance outcomes. For instance, strength and conditioning professionals may employ eccentric phase-emphasis strength training to retain or enhance strength over a scheduled break in training (e.g. holiday vacation). Conversely, conventional resistance training may be employed to enhance strength more acutely (e.g. peak for a competition in five days).

Eccentric phase-emphasis resistance training may have specific application for COD tasks that require large magnitudes of direction change – i.e. requiring full deceleration prior to overcoming inertia once more to accelerate in the new direction – particularly when total sprint time is the criterion measure. Prior to their use as monitoring tools, practitioners are encouraged to conduct sufficient familiarisation and establish reliability (thresholds of meaningful difference) of all assessments within the athletes to be trained.

Finally, practitioners are encouraged to monitor within-individual changes in performance measures to specifically address the needs of the athlete, and increase the likelihood of individual-specific performance enhancement.

Chapter 7 – The Influence of Short-term Multidirectional Jump Training on Jumping Performance and Change of Direction Tasks in Adolescent Rugby Union Players

Overview

Statistical associations between jump measures and 180-degree and 45-degree COD performance in football code athletes (Chapters 4 and 5) prompted investigating the efficacy of multidirectional jump training on performance in jumping and 180-degree and 45-degree COD tasks. Category- and task-specific responses following lower velocity strength training (Chapter 6) supported the examination of such responses following higher velocity speed-strength training in rugby union players. The primary aim of this study was to investigate the effects short-term multidirectional jump training had on jump and 180-degree and 45-degree COD performance. Secondly, category- and task-specific changes in performance measures were explored. The practical significance was providing insight into the short-term training responses in jump measures and COD measures following multidirectional jump training in adolescent rugby athletes.

Introduction

The primary responsibility of strength and conditioning practitioners is to employ training programmes that improve sports performance and reduce injury risk. In invasion sports, such as rugby union, a common focus in physical preparation is performance in COD tasks. Performance in generic and sport-specific COD tasks are suggested to coincide with performance outcome in competition (Gabbett, 2009; Green et al., 2011; Iacono et al., 2017; Marshall et al., 2014).

A critical step practitioners must take in planning is the identification of physiological and mechanical characteristics that underpin sport-specific demands (Chapter 2). Once identified, the selection of training modes that will facilitate the development of these characteristics is essential. Next, the timing of when in the training plan (e.g. preseason, in-season and post-season) these modalities are administered is important. Understanding the dose-response relationship these modalities have with athletic performance, such as COD capabilities with respect to when the intervention is administered, is equally important.

Jump training is widely accepted as an effective tool for developing athletic performance (Dos'Santos et al., 2017; Iacono et al., 2017; Loturco et al., 2015; Marshall & Moran, 2015; Miller et al. 2006; Thomas et al., 2009). This training mode provides practitioners a means of administering the neuromechanical overload needed for adaptation that is considered favourable for rapid, at-speed manoeuvres, such as changing sprint direction. Notably, jumps in the vertical and horizontal planes are proposed to share more similar mechanical constraints and determinants with COD tasks (Baker & Newton, 2008; Coh & Mackala, 2013; Marshall et al., 2014) (Chapters 2, 4, 5). Specifically, the loading at higher velocities generally associated with vertical and horizontal jumping may be more efficacious in improving performance across a broader array of COD tasks, (e.g. 180-degree and 45-degree COD), than the loading at slower velocities generally associated with strength exercises (Coh & Mackala, 2013; Marshall et al., 2014) (Chapters 4 and 5). In Chapter 5, preliminary associations between jump mechanics and 180-degree and 45-degree COD performance suggested multidirectional jump training would be effective in improving performance in COD tasks. This agreement between tasks may also facilitate sport-specific performance enhancement (Baker & Newton, 2008; Coh & Mackala, 2013; Marshall et al., 2014) (Chapters 2, 4, 5).

Jump training is a popular training modality due to high reliability, practicality and efficacy (Claudino et al., 2016; Claudino et al., 2013; Coh & Mackala, 2013; Iacono et al., 2017; Marshall & Moran, 2015; Popovic, 2016; Salonikidis & Zafeiridis, 2008). Considering the force-velocity relationship, jump training can offer sport-specific overload while potentially attenuating training fatigue when compared to its counterpart, heavy resistance exercise (Gamble, 2011). The acute and chronic neuromechanical stress jump training can provide would be specifically beneficial to rapid movements required in rugby codes. Practitioners can easily modify the imposed neuromechanical stress by varying the stretch rate and stretch load of the musculotendinous units involved in jumping (Coh & Mackala, 2013; Iacono et al., 2017; McBride, McCaulley, & Cormie, 2008).

The SJ, CMJ and DJ are jumps practitioners can seamlessly incorporate into the training plan (Castillo-Rodríguez et al., 2012; Iacono et al., 2017; Salonikidis & Zafeiridis, 2008). Because these jumps require different biomechanics and emphasise different muscle qualities, they can be used to vary the stretch rates and stretch loads experienced during training (Coh & Mackala, 2013; di Giminiani & Petricola, 2016; Iacono et al., 2017; Ishikawa & Komi, 2004; McBride et al., 2008). The CMJ, characterised by movement time (defined as the time from movement initiation to movement cessation) greater than 0.25 s, denotes lower-limb capability when eccentric and concentric actions are coupled (Iacono et al., 2017) (Chapter 2). The DJ, characterised by GCT (defined as the time interval from toe-down to toe-off) less than 0.25 s, denotes neuromotor function with a more rapid SSC (Iacono et al., 2017; Ishikawa & Komi, 2004) (Chapter 2). This neural component associated with DJ is considered most adaptable as modification to its activity has been observed well before other adaptations (Sale, 1988).

Several studies have demonstrated correlation between unloaded and loaded bilateral (Castillo-Rodríguez et al., 2012; Delaney et al., 2015; Thomas et al., 2009) (Chapter 2) and unilateral (Castillo-Rodríguez et al., 2012; Lockie, Schultz et al., 2014; Salonikidis & Zafeiridis, 2008) (Chapters 3, 4, 5) CMJ measures and performance in COD tasks. In Chapter 5, large task-specific association was found between unloaded unilateral CMJ measures and approach and total times of 180-degree and 45-degree COD tasks. ($r = -0.85$ to -0.62) in football code athletes. There are also data supporting an association between DJ measures and performance in COD tasks (Castillo-Rodríguez et al., 2012; Delaney et al.,

2015; Iacono et al., 2017; Marshall et al., 2014) (Chapter 5). In Chapter 5, large task-specific association was found between DJ measures and exit times of 180-degree and 45-degree COD tasks (r = -0.82 to 0.75) in football code athletes.

The relationship between a MDJ and 180-degree and 45-degree COD performance was examined in Chapters 3 and 4. The MDJ was relevant to the current study as it provides rapid accentuation of unilateral movement that is relative to individual anthropometrics (i.e. right-leg length). Chapter 3 revealed moderate to large correlation (r = -0.71 to -0.45) between MDJ distance and total time to complete 180-degree and 45-degree COD tasks. The MDJ distance was also successful in predicting total time to complete 180-degree and 45-degree COD tasks (p = 0.00 to 0.02). Collectively these relationships support the inclusion of MDJ where the training aim is to enhance COD capabilities in tasks requiring a 180-degree or 45-degree direction change.

The current investigation examined the short-term effects a combination (vertical, horizontal and lateral) multidirectional jump training intervention has on jump performance in adolescent rugby union athletes. The objective was to determine the effects jump performance enhancement elicited via combination multidirectional jump training has on COD capabilities in tasks requiring large (180-degrees) and more modest (45-degree) direction changes. Also examined were differential effects of changes in jump measures between sub-groups of individuals categorised as ‘fast’ (FAST) and ‘slow’ (SLOW) determined via baseline COD trial times (Chapters 4, 6).

Considering the findings of Chapter 4 (kinetic analysis of MDJ and COD tasks) and Chapter 5 (cross-sectional analysis of football code athletes), it was hypothesised combination vertical, horizontal and lateral multidirectional jump training would elicit a short-term enhancement in jump measures, with improvement in jump displacement in the horizontal plane (HCMJ and MDJ distance) being superior to that in the vertical plane (VCMJ, VJ20 and VDJ height). It was further hypothesised jump improvements would be concurrent with improvement in 180-degree and 45-degree COD performance. Lastly, it was hypothesised SLOW would achieve greater jump and COD improvements than FAST.

Methods

Experimental approach to the problem

A 4-week two-group repeated measures, crossover design was used to determine the efficacy of the jump training intervention. The following training schedule (Figure 7.1) was used for the first experimental group: pretest (week 0), 10 sessions of combination accentuated jump training, $posttest_1$ (week 5), followed by a 2-week wash-out period. $Pretest_2$ (week 8), 10 sessions of the control condition, and finally $posttest_3$ (week 13). The control condition was defined as the condition where participants continued their normal activities (e.g. rugby training and competitions) excluding the jump training intervention. It should be noted that the first control group followed the same schedule but with reverse conditions as stated above. Also, the training intervention (EXP) and control (CON) condition were administered in the last quarter of the in-season.

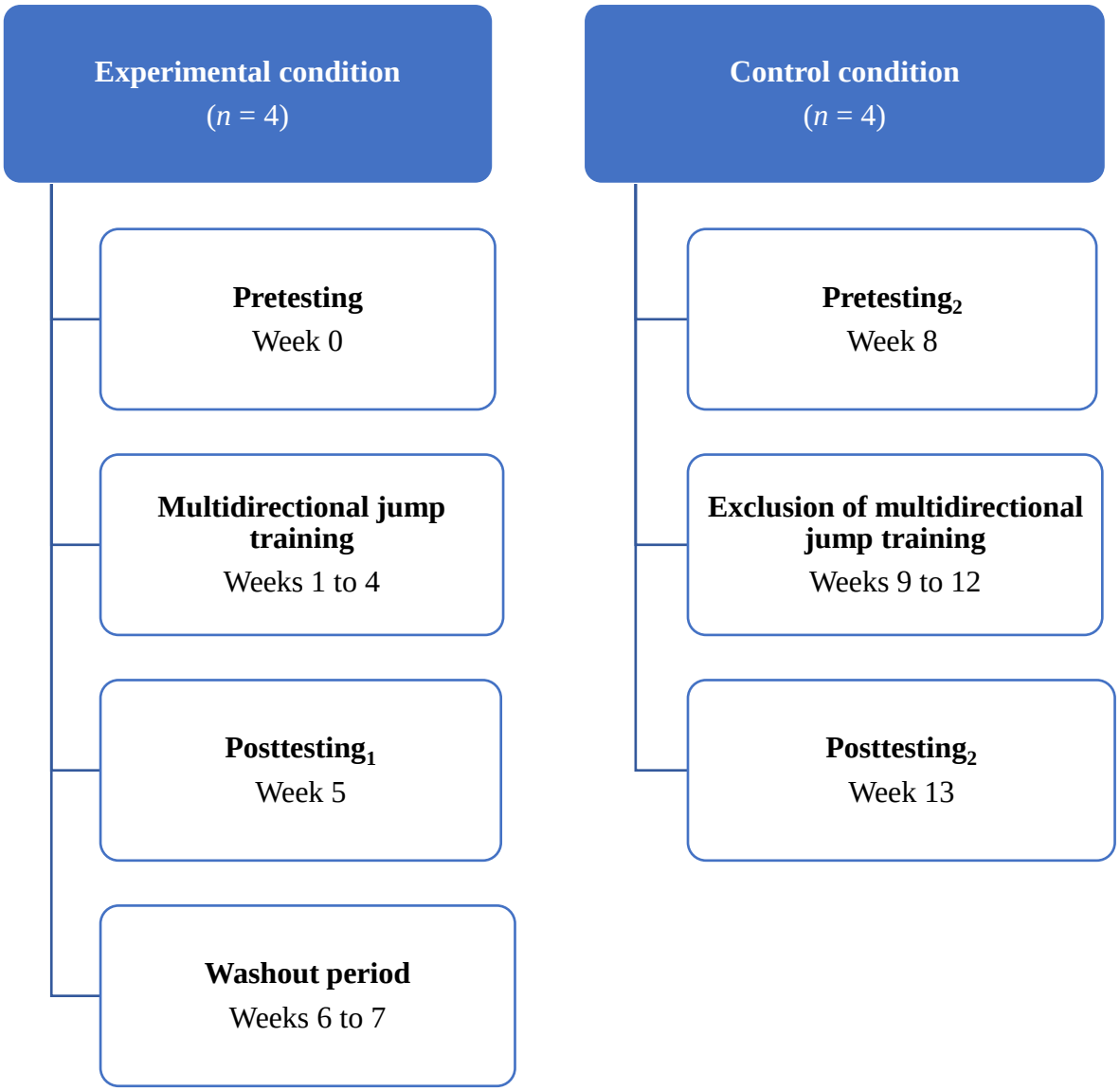

Figure 7.1. Training schedule for experimental and control conditions.

Subjects

Twelve male rugby union athletes began the study. However, only eight (chronological age: 16.3 ± 0.7 yr; mass: 73.8 ± 8.1 kg; height: 1.8 ± 0.1 m) achieved the necessary compliance of 100%. The cohort consisted of seven backs and one forward; all having at least 2 years of organised resistance training experience. Each participant had the benefits and risks of the investigation explained verbally and in written form, and signed an informed consent form before participation. The Auckland University of Technology Ethics Committee approved all procedures undertaken in this study (15/322).

Procedures

All participants were instructed to refrain from unusual or vigorous resistance exercise and cardiovascular activity prior to testing and during the wash-out period, and did not include any movements that were identical to any assessment or exercise encountered during testing and training. After anthropometry (height, mass and right-leg length) were measured, two 1-hour familiarisation sessions, separated by 24-hours, were conducted which included a standardised warm-up and identical tests described below, in the same order. The warm-up consisted of five minutes of submaximal jogging followed by five minutes of multi-joint dynamic stretches.

Day 1 of testing was 48 hours after the second familiarisation session. Prior to testing, assessment and plant-/contact-leg order were randomised and counterbalanced via blinded drawing to control order effects. Day 1 consisted of COD, vertical CMJ and vertical DJ testing, while Day 2 consisted of horizontal CMJ and MDJ testing. Test-retest reliability of COD and jump measures is shown in Table 7.1.

Anthropometrics

Body mass and body height were measured using a calibrated digital scale (HW-200KGL, A & D, CA, USA) and stadiometer (Holtain limited, Harpenden, Wales, UK), respectively. Next, using a previously described method (Mirwald et al., 2002) (Chapter 3), leg length was measured on the right leg from the greater trochanter to the lateral malleolus with a measuring tape and used to calculate 1.5 and 2.5 times leg lengths. All leg lengths were rounded to the nearest centimetre.

The age of peak height velocity (APHV) and years from APHV were derived from date of birth, standing height and seated height measurements, using a web-based calculator developed by the Saskatchewan Childhood Growth and Development Research Group (Saskatoon, Saskatchewan, Canada) [assessed 9 November 2016]. These measures of maturation were used to account for the relative stages of biological development among participants.

Table 7.1. Reliability of change of direction and jump displacement measures during experimental and control conditions.

	Unilateral performance measures			
	Left-leg measures		Right-leg measures	
Measure	Experimental %CV	Control %CV	Experimental %CV	Control %CV
180-degree approach time (s)	61.9	57.1	42.7	52.3
180-degree exit time (s)	84.2	113.2	57.3	88.6
180-degree total time (s)	1.6	2.4	2.2	2.5
45-degree approach time (s)	81.0	372.2	62.9	60.2
45-degree exit time (s)	9.2	11.2	78.3	12.5
45-degree total time (s)	4.4	5.5	3.0	5.1
Vertical DJ height (m)	5.9	9.3	21.2	5.3
MDJ x 1 leg-length distance (m)	0.5	0.7	0.8	0.8

MDJ x 1.5 leg-length distance (m)	0.5	0.8	0.5	0.8
MDJ x 2.5 leg-length distance (m)	0.7	1.5	0.8	0.6

Table 7.1 (cont.). Reliability of change of direction and jump displacement measures during experimental and control conditions

	Bilateral performance measures	
Measure	Experimental %CV	Control %CV
Vertical CMJ height (m)	4.4	2.4
Vertical JS height (m)	3.6	17.2
Vertical DJ height (m)	5.2	6.9
Horizontal CMJ distance (m)	3.2	2.8

%CV = coefficient of variation using typical error, DJ = drop jump, MDJ = multidirectional jump, CMJ = countermovement jump, JS = 20 kg jump squat.

Change of direction assessment

Change of direction capabilities in tasks that require relatively larger and more modest direction changes were assessed using 180-degree and 45-degree manoeuvres, respectively (Figure 3.1). Protocols were identical to those described in Chapter 6. Briefly, two trials per limb per assessment were allotted following two maximal effort familiarisation trials. Variables of interest were approach sprint time (i.e. sprint time prior to the plant-step), exit sprint time (i.e. sprint time after the plant-step) and total sprint time.

Jump assessments

Vertical jump assessment

Vertical jump testing was used to measure unloaded and loaded jump performance. Testing began with unloaded bilateral vertical CMJ (VCMJ) followed by 20 kg loaded vertical CMJ (VJS), 30 cm unloaded bilateral vertical DJ (VDJ30) and 15 cm unloaded unilateral vertical DJ (VDJ15).

For unloaded bilateral vertical CMJ participants placed a wooden dowel across the trapezius in a high-bar position, and told to self-select squat depth. When ready participants executed a jump for maximum height. The VJS was executed similarly to vertical CMJ except for a traditional 20 kg barbell. For all CMJ participants were instructed to jump for maximum height (Young, Pryor, & Wilson, 1995).

For both VDJ30 and VDJ15, participants placed their midfoot on the edge of the box, and instructed to “drop from the box and achieve maximum height following a short contact time” at their volition and land on both feet simultaneously (Young et al., 1995). The VDJ15 required the non-jump leg flexed approximately 90 degrees at the knee, hip and ankle. For all DJ tests arm swings were allowed to increase ecological validity and rate of familiarisation (Chapter 5).

Three attempts per jump were allowed with approximately 30 s rest between each trial. Participants were required to demonstrate postural control throughout the attempt, and land on both feet. If deemed unsatisfactory, another attempt was given. Tape was used to standardise the start position (CMJ) and landing area (DJ) in the centre of the force plate. A portable AMTI triaxial force plate (AccuPower, Advanced Mechanical Technologies,

Newton, MA, USA) using custom-built LabVIEW program (Version 14.0, National Instruments Corp, Austin, TX, USA) were used to collect stance-phase force-time data at 1000 Hz. Kinetic data were collected from a threshold of 30 N, normalised to body weight, and filtered with a 4th order 200 Hz low-pass Butterworth filter. Variables of interest were movement time (i.e. initial movement (CMJ) or toe-down (DJ) to toe-off), mean and peak eccentric and concentric force, negative and positive impulse, take-off velocity, and mean jump height.

Horizontal jump assessment

Bilateral horizontal CMJ (HCMJ) was used to measure unloaded horizontal jump performance. Participants placed their toes on the start line with arms extended and hand above the head. When ready a CMJ for maximum distance was executed. Arm swing was allowed (Chapter 5). Following two familiarisation trials two test trials were given. Distance was recorded to the nearest centimetre with the average jump distance used for analysis.

Multidirectional jump assessment

The MDJ task examined in Chapters 3 and 4 were used to measure accentuated unilateral horizontal jump ability (Figure 3.2). Methods used were identical to Chapter 3. Briefly, participants began in a bilateral stance facing the single-leg landing point located in a 0.30 m × 0.60 m contact area. When ready participants executed a bilateral horizontal CMJ, made ground contact with a single leg, immediately jumped 45 degrees to the contralateral side, then landed on two feet while simultaneously facing the new direction. Distances of the approach jump towards the contact area were equal to 1, 1.5 and 2.5 times leg-length with tape marking the respective start points. No preparatory step was allowed; however, no restrictions were placed on arm-swing or contralateral leg-swing. Participants were given three attempts on each leg at each leg length with 1 min rest between each attempt with the average distance used for analysis.

A high-speed digital camera (Casio, Exilim EX-FH20, Tokyo, Japan) was used assess the quality and distance of each jump. The camera was placed 4.5 m perpendicular to the 45-degree line that extended 3 m from the centre of the contact area (Figure 3.2). Distance of the unilateral jump (i.e. the second jump) was calculated by importing the video captured at

120 frames·s^{-1} into kinematic analysis software (Kinovea, version 0.8.15). The toe at first touchdown and heel at second touchdown of the jump leg served as the measurement points. The software was calibrated using a 1 m marking that was parallel to the 45-degree single-leg jump path. The variable of interest was unilateral jump distance.

Training protocol

During the multidirectional jump training intervention, participants completed 10 one-hour training sessions (Weeks 1 and 2 = three sessions per week; weeks 3 and 4 = two sessions per week) in addition to three and four two-hour non-research related rugby-specific resistance and practice sessions, respectively. Exercises during the training intervention consisted of loaded bilateral VJS, bilateral HDJ, unilateral vertical and horizontal (i.e. anterior) DJ, and the MDJ at all three leg-lengths. During the CON condition participants did not complete the additional jump training sessions; however, routine or normal activity was not interrupted. That is, school-related training and other activities were not restricted. Details of the exercises and periodisation are shown in Table 7.2. Similar to Chapter 6, loads lifted during training sessions were determined by individual ability, with weight selection guided by proper technique.

Table 7.2. Exercise selection and training volume progressions.

	Total session sets			Total session repetitions		
Warm-up exercises	Sessions 1 to 3	Sessions 4 to 6	Sessions 7 to 10	Sessions 1 to 3	Sessions 4 to 6	Sessions 7 to 10
Bilateral vertical CMJ	1	1	1	3	3	3
Bilateral 20 kg vertical JS	1	1	1	4	3	3
Intervention exercises	Sessions 1 to 3	Sessions 4 to 6	Sessions 7 to 10	Sessions 1 to 3	Sessions 4 to 6	Sessions 7 to 10
Bilateral vertical JS	7	7	7	12	12	15
Bilateral horizontal 30 cm DJ	7	7	7	9	9	9
Unilateral vertical 15 cm DJ	6	6	6	9	9	9
MDJ x 1.0 leg-length	2	2	2	6	6	6
MDJ x 1.5 leg-length	2	2	2	6	8	10
MDJ x 2.5 leg-length	2	2	2	6	6	6

CMJ = countermovement jump, JS = jump squat, DJ = drop jump, MDJ = multidirectional jump.

Load, defined as the amount of external mass lifted each set, was increased in the subsequent session if the athlete completed the respective lift correctly. However, loads were rounded down to the nearest 5 kg load, while load progressions were limited to 50% of body mass. This was done to ensure all athletes trained within the same relative range. Training volume (load × sets × repetitions) represented by arbitrary units (AU) was used to quantify training (Wernbom et al., 2007). Body mass was tracked to ensure accuracy in load selection, and account for potential influences on training load and responses. Session RPE (sRPE) was used as a subjective measure of training load (McGuigan & Foster, 2004; Singh et al., 2007), and collected and calculated identical to Chapter 6.

Statistical analysis

Statistical methods were identical to Chapter 6. Means ± SD were calculated to represent the centrality and spread of data. Confidence limits were set at 90% (90%CL). All force-time data were normalised to body weight (N). All variables were log transformed to reduce non-uniformity of error (Hopkins et al., 2009) with the mean of each variable used for analysis. The group median of total sprint times (calculated from the before-intervention data set) was used to segregate faster (FAST) and slower (SLOW) individuals to examine category differences (Hewit et al., 2013) (Chapters 3, 4 and 6). Percent changes in performance measures from pretest to $posttest_1$ of both conditions were calculated and compared. Within-participant SWC was determined via the comparison of individual percent change in mean and the CV (typical error relative to the group mean × 100). A SWC was noted if the percent change was greater than the average CV of score one and score two. Typical error was calculated by dividing the SD of the difference scores by the square root of two (Hopkins, 2000). Individual responses to each condition were quantified by standardised differences (ES) between performances following EXP and CON. Hedge's *g* ES were calculated to adjust for the small sample size according to Ialongo (2016). Standardised differences were also calculated to examine the accuracy of regression equations developed in Chapter 3 to predict 180-degree and 45-degree COD performance (Equations 1-12). Standardised difference thresholds of 0.20, 0.60, 1.20, 2.0 and 4.0 were used for small, moderate, large, very large, and extremely large, respectively (Hopkins et al., 2009).

Results

Anthropometry

Baseline measures of FAST (*n* = 4) were: chronological age = 17.0 ± 0.7 yr; peak height velocity = 13.6 ± 0.7 yr; years from peak height velocity = 3.6 ± 0.7 yr; right-leg length = 0.87 ± 0.1 m. Respective measures of SLOW (*n* = 4) were: 16.8 ± 0.6; 13.8 ± 0.6; 3.0 ± 0.6; 0.88 ± 0.04. Effect sizes for changes in anthropometrics between EXP and CON were trivial and small (FAST: chronological age = 0.10; mass = 0.15; standing height = 0.01; right-leg length = 0.00; SLOW: age = 0.16; mass = 0.46; standing height = 0.01; right-leg length = 0.00).

Training volume changes

Between-condition comparison showed jump squat training volume and sRPE were larger for SLOW (ES = 1.22 and 1.47, respectively). Within-group comparison of changes in activity not related to the study revealed FAST experienced a small increase (ES = 0.24), while SLOW experienced a moderate decrease (ES = -0.68). Between-group comparison showed small differences during EXP (ES = 0.51) and CON (ES = -0.37).

Jump assessment

Displacement and mechanical measures are in Tables 7.3 and 7.4, respectively.

Table 7.3. Comparison of percent changes in jump displacement following experimental and control conditions.

Measure	Unilateral displacement measures											
	Left-leg measures						Right-leg measures					
	Experimental % change		Control % change		ES		Experimental % change		Control % change		ES	
	Fast	Slow	Fast	Slow	Fast	Slow	Fast	Slow	Fast	Slow	Fast	Slow
Vertical DJ height (m)	-7.71	-12.13	0.16	-5.24	0.41[s]	1.59[l]	-3.80	-10.14	-7.61	-3.10	-0.13[t]	1.65[l]
MDJ x 1 distance (m)	0.45	6.37	6.94	1.44	3.45[vl]	-0.81[m]	2.41	2.67	2.45	1.70	0.01[t]	-0.20[s]
MDJ x 1.5 distance (m)	-0.40	8.35	9.75	1.11	5.56[el]	-0.82[m]	2.02	2.32	3.42	2.57	0.27[s]	0.07[t]
MDJ x 2.5 distance (m)	-0.11	8.25	7.21	2.32	2.72[vl]	-0.70[m]	2.98	4.25	5.53	3.88	0.44[s]	-0.04[t]

Measure	Bilateral displacement measures					
	Experimental % change		Control % change		ES	
	Fast	Slow	Fast	Slow	Fast	Slow
Vertical CMJ height (m)	-4.07	0.22	-3.79	24.67	0.03[t]	0.93[m]
Vertical JS height (m)	-1.38	3.64	6.30	-2.02	0.76[m]	-0.29[s]

Vertical DJ height (m)	-12.96	-12.44	1.23	-14.47	1.05[m]	-0.10[t]
Horizontal CMJ distance (m)	6.20	12.01	10.17	6.24	0.44[s]	-0.43[s]

m = moderate ES (0.60 to 1.20), l = large ES (1.20 to 2.0), vl = very large ES (2.0 to 4.0), el = extremely large ES (>4.0).

Table 7.4. Comparison of percent changes in jump kinetic measures following experimental and control conditions.

	Unilateral performance measures											
	Left-leg measures						Right-leg measures					
Measure	Experimental % change		Control % change		ES		Experimental % change		Control % change		ES	
Vertical drop jump	Fast	Slow	Fast	Slow	Fast	Slow	Fast	Slow	Fast	Slow	Fast	Slow
Contact time (s)	-9.20	22.42	-4.38	4.93	0.35[s]	-0.19[t]	-8.72	13.90	-0.87	24.84	0.25[s]	0.17[t]
Flight time (s)	-6.46	-10.10	-0.26	-4.35	0.39[s]	0.36[s]	-2.75	-8.56	-6.35	-2.58	-0.14[t]	0.36[s]
Neg. impulse (N·s)	-0.36	0.33	0.39	-0.88	0.17[t]	-0.21[s]	-0.64	5.57	1.50	-4.71	0.46[s]	-0.87[m]
Pos. impulse (N·s)	1.18	2.33	0.01	0.20	-0.40[s]	-0.74[m]	0.31	1.91	1.20	0.40	0.20[t]	-0.33[s]
Net impulse (N·s)	0.55	1.39	0.25	-0.15	-0.13[t]	-0.79[m]	-0.02	2.84	1.08	-1.73	0.28[s]	-0.77[m]
Take-off vel. ($m \cdot s^{-1}$)	8.01	19.04	-0.04	5.78	-0.40[s]	-0.46[s]	1.35	17.86	7.34	3.29	0.21[s]	-0.36[s]

Table 7.4 (cont.). Comparison of percent changes in jump kinetic measures following experimental and control conditions.

Measure	Bilateral performance measures					
	Experimental % change		Control % change		ES	
Vertical drop jump	Fast	Slow	Fast	Slow	Fast	Slow
Contact time (s)	-7.03	5.76	17.38	-4.29	0.74[m]	-0.14[t]
Flight time (s)	-10.65	-10.44	0.58	-9.53	0.97[m]	0.05[t]
Neg. impulse (N·s)	-0.20	0.88	0.26	0.24	0.18[t]	-0.28[s]
Pos. impulse (N·s)	1.38	1.60	0.03	1.29	-0.93[m]	-0.11[t]
Net impulse (N·s)	0.64	1.03	-0.07	0.70	-0.75[m]	-0.30[s]
Take-off vel. ($m \cdot s^{-1}$)	6.63	9.42	-1.26	7.84	-0.83[m]	-0.09[t]
Vertical jump squat						
Flight time (s)	-1.61	-7.76	-29.24	4.97	-1.45[l]	0.71[m]

Neg. impulse (N·s)	0.08	-0.52	2.57	0.38	1.18[m]	0.19[t]
Pos. impulse (N·s)	0.02	2.45	18.35	0.45	1.80[l]	-0.72[m]
Net impulse (N·s)	0.21	5.49	25.25	0.48	1.64[l]	-0.50[s]
Take-off vel. ($m \cdot s^{-1}$)	1.33	-2.45	-11.58	3.73	-1.51[l]	0.32[s]

m = moderate ES (0.60 to 1.20), l = large ES (1.20 to 2.0), vl = very large ES (2.0 to 4.0), el = extremely large ES (>4.0).

Countermovement jump displacement

Neither group showed improvement in VCMJ height following EXP. SLOW showed a moderate improvement in all left-leg MDJ distances following EXP (ES = -0.82 to -0.70).

Drop jump height

Neither group showed improvement in bilateral or unilateral VDJ height following EXP.

Countermovement jump mechanics

FAST showed a very large improvement in bilateral VCMJ take-off velocity following EXP (ES = -2.05). FAST also showed a large improvement in VJS flight time and take-off velocity, following EXP (ES = -1.45 and -1.51, respectively). SLOW showed a moderate improvement in VJS positive impulse following EXP (ES = -0.72).

Drop jump mechanics

FAST showed a moderate improvement in bilateral VDJ contact time, take-off velocity, positive impulse, net impulse (ES = -0.93 to 0.74). SLOW showed a moderate improvement in left-leg VDJ positive impulse and net impulse (ES = -0.74 and -0.79, respectively), and moderate improvement in right-leg mean eccentric force, negative impulse, net impulse (ES = -0.87 to -0.77) following EXP.

Change of direction assessment

COD results are shown in Table 7.5.

For left-leg tasks, FAST showed a moderate and large improvement in left-leg 45-degree approach and exit time (ES = 0.69 and 1.74, respectively), while SLOW showed a moderate improvement in left-leg 45-degree total time (ES = 0.65) following EXP.

For right-leg tasks, SLOW showed a moderate and large improvement in 180-degree approach and total time following EXP (ES = 1.02 and 1.48, respectively).

Regression analysis

Across all test points (i.e. EXP and CON pretest and posttest) trivial to small differences were found between predicted and actual 180-degree (ES = -0.49 to 0.31) and 45-degree (ES = -0.19 to 0.54) COD total sprint times when using MDJ performance scores.

Table 7.5. Comparison of percent changes in 180-degree and 45-degree change of direction performance measures following experimental and control conditions.

	Left-leg change of direction measures			Right-leg change of direction measures		
Measure	Experimental % change	Control % change	ES	Experimental % change	Control % change	ES
180° approach time (s)						
Fast	201.83	57.68	-0.30[s]	-54.97	-33.75	0.05[t]
Slow	-25.57	-18.86	0.14[t]	-40.13	150.98	1.02[m]
180° exit time (s)						
Fast	-37.22	-0.86	0.30[s]	-78.50	-118.37	-0.21[s]
Slow	-38.52	-17.96	0.33[s]	-17.06	-121.97	-0.88[m]
180° total time (s)						
Fast	0.09	-1.94	-0.43[s]	1.79	-2.35	-1.15[m]
Slow	-1.28	1.23	0.37[s]	-1.47	7.02	1.48[l]

Table 7.5 (cont.). Comparison of percent changes in 180-degree and 45-degree change of direction performance measures following experimental and control conditions.

Measure	Left-leg change of direction measures			Right-leg change of direction measures		
	Experimental % change	Control % change	ES	Experimental % change	Control % change	ES
45° approach time (s)						
Fast	-45.37	39.39	0.69[m]	-37.36	-66.95	-0.17[t]
Slow	-86.94	-275.27	-0.20[s]	118.85	-33.38	-0.10[t]
45° exit time (s)						
Fast	-24.75	10.37	1.74[l]	-2.70	1.32	0.11[t]
Slow	-1.72	-11.00	-0.40[s]	126.45	3.99	-0.30[s]
45° total time (s)						
Fast	11.05	-3.71	-2.24[vl]	5.30	4.79	-0.02[t]
Slow	-1.69	4.37	0.65[m]	-7.21	1.57	0.58[s]

m = moderate ES (0.60 to 1.20), l = large ES (1.20 to 2.0), vl = very large ES (2.0 to 4.0), el = extremely large ES (>4.0).

Absolute performance change analysis

Absolute change in jump displacements showed moderate and large improvements in left-leg MDJ distances in FAST (ES = 1.10 to 1.84 vs. 1.10 to 2.11), while SLOW showed benefit in both left- and right-leg MDJ distances (ES = 2.97 to 3.49 vs. 0.44 to 0.90 and 1.37 to 1.75 vs. 1.33 to 1.50, respectively). FAST and SLOW each showed greater improvements in HCMJ distance following EXP (ES = 1.19 vs. 1.16 and 1.21 vs. 1.02, respectively). FAST and SLOW also showed benefit in bilateral VDJ height (ES = 0.79 vs. -0.06 and 1.46 vs. 1.27, respectively). Unilateral performance showed FAST benefited in left-leg VDJ height (ES = 0.69 vs. -0.01), while SLOW benefited in left- and right-leg VDJ height (ES = 1.30 vs. 0.67 and 0.76 vs. 0.55, respectively).

Absolute change in jump mechanics showed SLOW benefited in unloaded VCMJ negative, positive and net impulse (ES = 0.83 to 1.40 vs. -0.23 to 0.37), and in VJS positive and net impulse (ES = 0.77 and 0.78 vs. 0.21 and 0.24, respectively). FAST and SLOW showed benefit in flight time (ES = 0.78 and 1.46 vs. -0.02 and 1.05, respectively) and vertical take-off velocity (ES = 0.79 and 1.45 vs. -0.22 and 1.02, respectively) in bilateral VDJ. Unilateral VDJ showed FAST benefited in left-leg flight time (ES = 0.70 vs. 0.03), while SLOW benefited in left- and right-leg flight time (ES = 1.30 and 0.91 vs. 0.67 and 0.55) and vertical take-off velocity (1.29 and 0.94 vs. 0.69 and 0.56, respectively).

Absolute change in COD performances revealed FAST improved in approach (ES = -1.83 vs. -0.76) and exit (ES = -0.94 vs. -1.48) times following EXP in the right-leg 180-degree COD task. Similarly, SLOW experienced greater improvements in approach (ES = -1.10 vs. -0.52) and exit (ES = -0.69 vs. 0.04) times in the left-leg 180-degree COD task. Only SLOW showed benefit in approach (ES = -2.55 vs. 1.41) and exit (ES = -2.56 vs. 0.21) times in the right-leg 45-degree COD task.

Discussion

The primary finding of this study was favourable short-term changes in jump and COD measures following 10 1-hour sessions of adjunct multidirectional jump training. The second major finding was that changes appeared to be group- and task-specific. Lastly, all regression equations of Chapter 3 were successful in predicting performance outcome (trial time) in 180-degree and 45-degree COD tasks across four time-series data sets (i.e. EXP and CON pretest and posttest).

Of particular interest was the difference in results when percent changes and absolute changes were examined. Specifically, percent change analysis rendered 14 total observations of meaningful difference between EXP and CON, while absolute change analysis rendered 26 observations of meaningful between-condition differences.

An aim of this study was to examine what jump measures are influenced by this mode of short-term adjunct jump training. Interestingly, regardless of analysis approach, more DJ measures showed improvement than CMJ measures following this short-term adjunct jump training. The greater short-term influence this training mode had on DJ measures can be explained by the principle of specificity. It is well documented that specificity in movement pattern and contraction type is essential in increasing the likelihood of positive performance outcome (Bain & McGown, 2010; Davids et al., 2006; Sale, 1988). Given most of the short-term changes occurred in DJ measures, the training mode used in this study appears to have replicated the rapid stretch-shortening actions experienced in competition.

Another aim was to examine the influence category (i.e. FAST vs. SLOW) may have on short-term improvements in jump measures. This comparison supported the hypothesis that this mode of jump training would elicit greater improvements in SLOW when compared to their FAST counterparts. Category-specific differences have been observed in cross-sectional (Chapters 4 and 5) and training intervention (Chapter 6) studies. Relative to this study, Chapter 6 showed SLOW experienced greater improvement in 180-degree and 45-degree COD performance following 6-week eccentric phase-emphasis strength training intervention. Also between-group comparison showed SLOW experienced larger changes in training intervention volume (ES = 1.22) and sRPE (ES = 1.47). Within-group comparison of non-training intervention related activity showed FAST experienced a small increase (ES = 0.24), while SLOW experienced a moderate decrease (ES = -0.68). The higher training intervention volume

coupled with higher sRPE and decrease in non-training intervention activity suggest SLOW may have accumulated fatigue. The relationship between COD capabilities, training intervention related activity, perceived exertion and non-training intervention activity had been previously observed in Chapter 6. In the eccentric training study SLOW showed an extremely large decrease in lower-limb training volume (ES = -4.38) and a large increase in sRPE (ES = 1.82) during 6 weeks of eccentric phase-emphasised training.

The findings of this study support the use jumps that involve stretch rates and loads beyond that experienced during a single-effort static-start unloaded CMJ, as a potential means of acutely enhancing performance in jump and COD tasks (i.e. approach and exit sprints). Recently, cross-sectional and intervention research demonstrated favourable relationships between vertical and horizontal jump measures and COD capabilities (Iacono et al., 2017; Lockie, Schultz, et al., 2014; Meylan et al., 2009; Ramírez-Campillo et al., 2015) (Chapters 3, 4 and 5). Lockie et al. (2014) demonstrated relationships between horizontal jump measures and total sprint time in COD tasks that require sequential 180-degree and 90-degree, and sequential 90-degree and 45-degree COD-steps. Similarly, Chapter 5 noted task-specific association between vertical and horizontal jump measures and time to complete discrete 180-degree and 45-degree COD tasks. Chapter 5 also noted vertical CMJ and DJ jump measures successfully distinguishing forwards from backs.

Though longer in duration (8 weeks and 6 weeks vs. 4 weeks), recent training intervention studies that incorporated jump training during the in-season phase of the macrocycle offer support for the findings of this study (Iacono et al., 2017; Meylan & Malatesta, 2009; Ramírez-Campillo et al., 2015). Following eight weeks of forwards-backwards and side-to-side plyometric training during the in-season, Meylan and Malatesa (2009) observed significant improvement (9.6% decrease in trial time) in a COD task that required four 60-degree direction changes in a cohort of soccer players (n = 14, age = 13.3 ± 0.6 yr). Similarly, Ramírez-Campillo and colleagues (2015) observed moderate improvement (ES = -0.66) in the same COD assessment employed by Meylan and Malatesa (2009) following 6 weeks of bilateral and unilateral multidirectional jump training during the in-season in a cohort of soccer players (n = 12, age = 11.6 ± 2.7 yr).

Recently, the reliance on training factors identified as determinants for favourable performance outcome from data gained via cross-sectional analysis has been questioned

(Marshall & Moran, 2015). Marshall and Moran investigated the relationship cross-sectional data has with pre- to post-training change data (Marshall & Moran, 2015). Their results indicated the use of cross-sectional data should be used in addition to test-retest change data to determine important factors such as exercise selection, training foci and the overarching structure and scheduling of training. The lack of improvement in jump measures deemed meaningful and statistically associated with 180-degree and 45-degree COD performance in Chapter 5, such as eccentric force during VDJ, supports the recommendation of Marshall and Moran, and highlights the need to use both cross-sectional and test-retest data when planning training (Marshall & Moran, 2015) (Chapter 6).

Improvement in performance variables following this mode of jump training appears to be task- and category-specific. Specific improvements in bilateral and unilateral VDJ flight time, take-off velocity and jump height, HCMJ distance and approach and exit times about the 180-degree COD were noted for both categories following EXP. On the other hand, specific improvements in VCMJ and VJ20 impulse, MDJ distance and approach and exit time about the 45-degree COD were noted for slower individuals exclusively. The findings of this study agree with Chapter 6 findings which similarly demonstrated category-specific (i.e. slow individuals) and task-specific (i.e. 180-degree COD tasks) improvement following a 6-week eccentric phase-emphasis training intervention in a similar cohort.

The relationships observed between training mode (jump vs. strength) and COD performance (180-degree vs. 45-degree COD) can be explained by the principle of training specificity (Iacono et al., 2017; Sale, 1988). This principle states meaningful improvement and performance retention in the criterion task is more likely to occur when the dynamical intent of the criterion and training tasks correspond (Iacono et al., 2017; Sale, 1988; Schmidt & Lee, 2013). Notably, the jump training used in this study improved bilateral and unilateral positive and net impulse *and* take-off velocity in both FAST and SLOW athletes. Enhancements in impulse and velocity capabilities is considered advantageous in any sports setting as these components are fundamental to all physical activities (Kirby, McBride, Haines, & Dayne, 2011; Winter et al., 2016), and should ‘transfer’ to in-competition performance (McBride et al., 2008; Winter et al., 2016). Relative impulse during the propulsive phase is suggested to offer a more accurate measure and explanation of inter-individual differences in athletic manoeuvres (Kirby et al., 2011; Winter et al., 2016). The findings of this study support this posit as

impulse, and the closely related take-off velocity, displayed favourable short-term changes in both faster and slower individuals.

Unexpected was the general absence of improvement in force production and jump height despite improvements in impulse and take-off velocity. Disassociation between jump kinetics and jump height has been previously demonstrated acutely in recreationally trained individuals (Kirby et al., 2011), basketball and volleyball players (McBride et al., 2008) and American football players and track athletes (Nuzzo, McBride, Cormie, & McCaulley, 2008), and following long-term training in Australian football players (McGuigan, Cormack, & Newton, 2009). This disconnect between peak force and performance outcome (i.e. jump height) has been attributed to differences in selected squat depth during the jump and other aspects of the technical application of force (Kirby et al., 2011). During this study squat depth was not rigorously controlled to increase ecological validity within practical settings. Consequently, inter- and intra-individual differences in technique may have contributed to the lack of association jump measures had with COD capabilities.

A recurrent finding of this thesis is relatively high variation in approach and exit times compared to the relatively low variation in total times of both 180-degree and 45-degree COD tasks (Chapters 3, 4, 5 and 6). Recently, the sprint paths selected in 10 cyclical forwards and backwards 3 m sprints demonstrated marked between- and within-individual variation (Arshi et al., 2015). In this study, the estimation of true changes in approach and exit times were difficult to determine due to high variation within the measure, while that of total time were more apparent due to lower variation within the measure (CV = 1.6 to 5.5%). A similar cohort (high-school rugby athletes: n = 12, age 15.0 ± 0.9 yr, mass 80.2 ± 15.3 kg, height 1.8 ± 0.1 m) and a dissimilar cohort (club-level athletes from multiple sports: n = 20, age: 27.5 ± 5.9 yr; body mass: 79.2 ± 11.8 kg; height: 1.8 ± 0.1 m) have also demonstrated notable differences in variation when approach and exit time CV are compared with total time CV (Chapters 3, 4, 5 and 6). Variation in rapid tasks about a COD-step (Arshi et al., 2015; Iacono et al., 2017; Qiao et al., 2014) (Chapters 3, 4, 5 and 6) and total time to complete a COD task (Meylan et al., 2009; Oliver & Meyers, 2009; Stewart et al., 2014) (Chapters 3, 4, 5 and 6) have been reported. The relative stability of the measure of total time can be attributed primarily to genetic influences often associated with ability to successfully complete COD tasks (Schmidt & Lee, 2013). Conversely, the disparity in stability of measurement can be attributed to the high variation in the selection and execution of

approach and exit strategies (Arshi et al., 2015; Qiao et al., 2014) (Chapters 3, 4, 5 and 6); suggesting 'pre-planned' tasks include an element of decision making and perception-action coupling often exclusively associated with agility (Sheppard et al., 2014; Sheppard & Young, 2006; Young & Farrow, 2013) (Chapter 2).

The relatively high variability in this and other studies also highlights the occurrence of individual-specific responses to training intervention (Claudino et al., 2016) (Chapter 6). Individual-specific responses to eccentric phase-emphasis strength training were seen in Chapter 6. In that study and the present, solely examining group data would have disguised meaningful individual-specific test-retest changes (Claudino et al., 2016; Claudino et al., 2013; Marshall & Moran, 2015) (Chapter 6). For example, there were moderate and large standardised differences between experimental and control conditions in vertical jump measures in each category. However, consistency of positive responses within a measure of a given group was reduced due to different within-individual responses (Marshall & Moran, 2015; Meylan & Malatesta, 2009; Popovic, 2016). It is suggested these individual-specific responses are influenced by intrinsic properties, such as musculotendinous architecture and neuromuscular composition (Marshall & Moran, 2015; Popovic, 2016; Schmidt & Lee, 2013). Consideration of monitoring meaningful changes with respect to a defined category *and* the individual is advised as primarily genetic influenced factors are suggested to underpin inter-individual differences observed in the execution of athletic manoeuvres (Marshall & Moran, 2015; Meylan & Malatesta, 2009; Popovic, 2016; Schmidt & Lee, 2013).

There are limitations that should be acknowledged. First, the findings are limited to the cohort of this study, and should not be generalised to populations differing in biological and training age (Chapters 3 and 6). Second, results from this short-term intervention study are limited to investigations of "acute short-term enhancement" (Dobbs, Gill, Smart, & McGuigan, 2017). More research investigating longitudinal responses and subsequent long-term adaptation in both jump and COD measures following this mode of multidirectional jump training is warranted.

Practical Applications

Multidirectional jump training is a practical method for administering an overload stimulus which facilitates advantageous sports-specific muscle function in a safe manner in youth rugby union athletes. The training mode in the current study may offer an additional strategy for effecting favourable acute performance outcomes. For

instance, to enhance critical bilateral and unilateral jump measures, such as impulse and take-off velocity, more acutely (e.g. peak for a competition in 4 weeks) strength and conditioning professionals may employ a combination of single-effort and multi-effort vertical and horizontal jumps in addition to scheduled resistance and sports-specific training.

Jump training including single-effort and multi-effort multidirectional manoeuvres has application for COD tasks that require both large and more modest magnitudes of direction change, particularly when acute changes in total sprint time is the criterion measure. Prior to their use as monitoring tools, however, practitioners are encouraged to conduct sufficient familiarisation and establish reliability (thresholds of meaningful differences) for all suggested assessments within the athletes to be trained.

Finally, practitioners are encouraged to monitor within-individual changes in performance measures to specifically address the needs of each athlete. This also entails collecting and comparing training intervention data with cross-sectional data within the cohort of athletes. This comprehensive approach should increase the likelihood of individual-specific performance enhancement.

Chapter 8 – Summary, Practical Applications and Future Research Directions

Summary

The primary aim of this thesis was to improve understanding of COD tasks in the context of Newtonian physics – particularly, the impulse-momentum relationship – and give insight to the context-specific relationship between constraints and performance determinants generally associated with COD tasks. The overarching purpose was to investigate training approaches hypothesised to enhance COD capabilities in rugby union players. The underlying objective was to provide practical evidence-based methods to improve current methods of assessment, statistical treatment and training programming for rugby union athletes. Due to the inherent feature of COD tasks in field- and court-based sports (Brughelli et al., 2008; Sheppard et al., 2014; Sheppard & Young, 2006) recommendations from this thesis are potentially applicable to invasion/evasion athletes of developmental, club, regional, professional and elite populations.

The research question of this thesis was, "how can performance in COD tasks be enhanced in rugby union athletes?" The first step in answering this question was the identification of task-specific mechanical constraints and determinants as well as individual-specific neuromuscular characteristics associated with generic and sport-specific COD tasks. An extensive review of the literature and synthesis of results (Chapter 2) led to the following findings:

1) A significant association exists between strength, speed-strength and COD capabilities (Delaney et al., 2015; Iacono et al., 2017; Spiteri et al., 2014; Suchomel et al., 2016; Watts, 2015), however these relationships may vary with context (e.g. a velocity change in series with a jump and sprint);

2) Key factors that should be accounted for when assessing and training COD capabilities are biological and training age, body mass, sport and playing position (Condello et al., 2013; Delaney et al., 2015; Yanci et al., 2014);

3) High-load (lower velocity) and low-load (higher velocity) strength training with a progression from bilateral to unilateral emphasis may be needed to improve COD capabilities (Brughelli et al., 2008; Sheppard et al., 2014);

4) Training that includes multidirectional jump training appears to influence performance in tasks that are in series with the COD plant-step (e.g. straight-line sprints) (Delaney et al., 2015; Dobbs et al., 2015);

5) COD training should quickly progress from COD tasks with lower contextual interference to COD tasks with higher contextual interference and more representative of competition (Davids et al., 2006; Holmberg, 2009).

For measures to be considered practical, the reliability and precision of measurement must be considered and established (Hopkins et al., 2009; Hopkins, 2000; McGuigan, 2017). Study 3 determined the reliability and precision of the COD and novel MDJ performance measures used in this thesis. The COD performance measures were sprint times of the approach, exit and total sprints in 180-degree and 45-degree tasks that required direction changes with left and right plant-legs. The criterion COD measure, however, was total sprint time. The MDJ performance measures were approach jump time and distance of the contralateral (45-degree) unilateral jump that followed an individualised bilateral horizontal CMJ. The findings of the test-retest reliability analysis on individual- and team-sport players (n = 20) (Chapter 3) were as follows:

1) High correlation between MDJ and COD performance suggests MDJ can be used as a training tool to enhance COD capabilities;

2) High shared variance between MDJ unilateral jump distance and COD performance suggests MDJ performance can be used to monitor, predict and train 180-degree and 45-degree COD capabilities;

3) Following sufficient familiarisation two or three test trials may be sufficient for estimating true performance scores, however the requisite accuracy and precision of these measures may vary with cohorts.

To investigate factors that potentially underpin performance in the COD (total time) and MDJ (jump distance) tasks, respective plant-step force-time measures were analysed. Also of interest were force-time measures that distinguished faster and slower individuals in COD tasks. The findings of a cross-sectional analysis of individual- and team-sport players (n = 19) (Chapter 4) were as follows:

1) COD plant-step kinetics distinguished faster and slower individuals;

2) MDJ plant-step kinetics and jump distance distinguished faster and slower individuals;

3) COD plant-step kinetics were task-specific – that is, 180-degree COD total time was associated with higher magnitudes of plant-step Fy and Fz, while 45-degree COD total time was associated with higher magnitudes of plant-step Fx and Fz;

4) Correlation and shared variance between MDJ and COD performances support the findings of Chapter 3.

Force capacity and capabilities were associated with faster performances in COD tasks (Chapter 2). To determine exercise selection and programming schemes of subsequent training intervention studies (Chapters 6 and 7), several strength and speed-strength measures associated with COD capabilities were analysed. Also of interest were strength and speed-strength measures that distinguished forwards and backs. The findings of a cross-sectional analysis of football code forwards (n = 6) and backs (n = 6) (Chapter 5) are as follows:

1) Vertical impulse and take-off velocity during CMJ and DJ were associated with faster 180-degree and 45-degree COD performance;

2) The relationships vertical and horizontal CMJ and DJ measures shared with COD performance were task-specific – that is, CMJ measures were associated with performance in pre-plant-step tasks (i.e. approach sprint) and overall performance (summation of approach and exit sprints) regardless of velocity change magnitude, while DJ measures were associated with performance in post-plant-step tasks (i.e. exit sprint) of the 45-degree COD task;

3) The majority of CMJ and DJ measures associated with category-specific performance were from vertical speed-strength tasks;

4) The 45-degree COD tasks successfully distinguished forwards and backs.

Using the literature review and cross-sectional data, strength (Chapter 6) and jump (Chapter 7) training interventions were designed to improve COD capabilities in rugby union players. Training mode selection and related methodologies were predicated on utility in general rugby settings. Specifically, the consideration of facilities (e.g. space and equipment) and other limitations (e.g. practitioner competence and limited time with athletes) were of utmost importance during the development and employment of the training interventions of this thesis. Also of interest were the task-specific and category-specific responses associated with respective training modes.

The association between vertical eccentric force-time measures and COD measures in Chapter 5 prompted the investigation of the influence a practical eccentric training modality has on 180-degree and 45-degree COD capabilities. A 6-week eccentric phase-emphasis strength training intervention using free-weight exercise (n = 12) (Chapter 6) revealed:

1) Resistance training with controlled 3-second eccentric activity was effective in retaining and enhancing peak relative isometric strength following a 3-week cessation;

2) Resistance training with self-selected eccentric activity was effective in enhancing strength more acutely (i.e. immediately after training, and before the 3-week cessation);

3) Eccentric phase-emphasis strength training selectively enhanced 180-degree COD performance;

4) Slower individuals experienced greater strength and COD improvement than their faster counterparts;

5) Training responses were category-specific, however, training responses varied between- and within-individuals independent of category.

Association between vertical and horizontal jump measures and COD capabilities in Chapters 3, 4 and 5 prompted the investigation of the influence a multidirectional jump training modality had on 180-degree and 45-degree COD performance. Of interest was the short-term utility of this adjunct training mode in sustaining or enhancing jump and COD capabilities in-season. A 4-week accentuated multidirectional jump training investigation (n = 8) (Chapter 7) revealed:

1) The addition of accentuated jump training to the usual training regime was effective in the short-term enhancement of CMJ and DJ measures, particularly vertical impulse and take-off velocity;

2) More observations of improvement were noted for DJ measures than CMJ measures;

3) The short-term enhancement in CMJ and DJ measures was accompanied by improvement in post-plant-step tasks of the 45-degree COD manoeuvre (i.e. exit sprints);

4) Slower individuals experienced greater jump and COD improvement than their faster counterparts;

5) Training responses were category-specific, however, training responses varied between- and within-individuals independent of category.

Practical Applications

A common challenge encountered by team-sport strength and conditioning practitioners is the enhancement of athletic proficiency (Bourgeois et al., 2017; Holmberg, 2009; Smith, 2003). This regarded movement proficiency is ultimately underpinned by the appropriate use of generated force in context-specific performance during competition (Bain & McGown; Bourgeois et al., 2017; Davids et al., 2006; Holmberg, 2009). Furthermore, COD assessments are a common feature in test batteries and often aid in talent identification and team selection (Pyne et al., 2006; Sierer et al., 2008; Stewart et al., 2014). Therefore, answering the overarching question of this thesis was governed primarily by improving practice with relatively simple evidence-based methods. As a result, the following recommendations are offered to improve performance in COD tasks:

- Identify features such as test duration, number of direction changes and magnitudes of direction changes. These assessment-specific characteristics will dictate respective performance determinants (Schot et al., 1995; Spiteri et al., 2015; Young et al., 2002).
- Consider anthropometrics, such as biological age, training age and body mass, when investigating performance in COD tasks and determining the sequence of training modes, volumes and intensities, and scheduling of progressions towards representative training (Condello et al., 2013; Davids et al., 2006; Holmberg, 2009).
- Consider a particular focus on strength training to increase force generating capacity for enhancing performance in COD tasks that require larger velocity changes (i.e. ≥90-degree COD) (Jones et al., 2009; Spiteri et al., 2015; Spiteri et al., 2014). Full-body conventional strength training where eccentric and concentric activity are self-selected may have a more acute effect on strength capacity. Conversely, eccentric phase-emphasis strength training where eccentric activity is controlled to three seconds may have a delayed effect, and provide a stimulus for greater strength retention and development.

- Consider a particular emphasis on speed-strength training to enhance a broader spectrum of COD capabilities (i.e. 0-degree to 180-degree COD tasks) (Castillo-Rodríguez et al., 2012; Iacono et al., 2017; Jones et al., 2009; Lockie, Schultz, et al., 2014; Markovic, Jukic, Milanovic, & Metikos, 2007; Peterson et al., 2006; Spiteri et al., 2013; Spiteri et al., 2015; Suzuki et al., 2014). Use of CMJ exercise may improve performance in pre-plant-step tasks that entail closing speed (i.e. approach speed) and overall COD performance (total time) regardless of magnitude of velocity change. Conversely, DJ exercise may be used to improve performance in post-plant-step tasks (e.g. exit speed) that require more modest velocity change such as cutting tasks. Also, ground contact time and the technical application of force should be emphasised during the execution of speed-strength training exercises.
- Vertical jump tasks may be sufficient for enhancing and monitoring COD capabilities. However, the combination of vertical and horizontal jumps is recommended for a more comprehensive assessment of task-specific force capabilities and their respective relationships with COD measures.
- Consider the individualised MDJ tasks of Chapter 3 to improve COD capabilities, notably performance in cutting tasks (e.g. 45-degree COD), with an emphasis on Fy and Fz capabilities when seeking to enhance performance in tasks requiring ≥90-degree direction changes, and an emphasis on Fx and Fz capabilities when aiming to enhance performance in tasks requiring ≤90-degree direction changes.
- Consider adjunct multidirectional jump training to elicit acute improvements in jump measures such as vertical impulse and take-off velocity, and enhance performance in post-plant-step tasks.
- Consider training representative (i.e. ecologically valid) COD tasks developed via video analysis of competition when seeking to enhance COD performance (Bourgeois et al., 2017; Davids et al., 2006). Training these identified tasks should be guided by emphasis on context-specific environmental stimuli, postures and inter-segment coordination (Bartlett et al., 2007; Bourgeois et al., 2017; Holmberg, 2009).
- Consider establishing the reliability and precision of assessment and training tools as selected measures will be used to monitor and modify short-term and long-term training strategies (Hopkins et al., 2009; Hopkins, 2000; McGuigan, 2017). Also, the accuracy and precision of between- and within-individual

measurements should also be established at all test points within the same cohort, and re-established as cohorts change.

Future Research Directions

Considering the findings and limitations of this thesis, the following recommendations can be offered for future research:

- Consideration of individual-specific performance profiles and training responses when investigating force and COD capabilities is warranted. A recurrent observation in this thesis was relatively high between- and within-individual variation in performance measures, particularly approach and exit sprint times of the COD assessments. Relatively high between- and within-individual variation has been observed in high-speed actions such as javelin and discus throwing (Bartlett et al., 2007), multi-effort forwards-backwards 3 m sprinting (Arshi et al., 2015), running (Bartlett et al., 2007) and COD tasks (Schot et al., 1995). This variance associated with high-speed complex tasks should be considered in future research using differential methods (i.e. individual differences analysis) to examine COD capabilities and mode-specific training responses (Bartlett et al., 2007; Schmidt & Lee, 2013).
- Experimental approaches based on task "representativeness" – that is, tasks that correspond with, or 'represent,' criterion task regulatory stimuli, energy systems and mechanical profiles (Bain & McGown, 2010; Brunswick, 1956; Davids et al., 2006) – should be used in future investigations. The selection of assessment measures should be guided primarily by ecological validity with criterion COD performance measures that are context appropriate. Examining general and position-specific criterion COD performance measures from an ecological or contextual perspective will assist in the continued development of COD training methods that are based on sound motor learning and control principles (Bain & McGown, 2010).
- More research examining COD training progressions from tasks with lower contextual interference to tasks with higher contextual interference (i.e. competition-specific) is needed. Furthermore, more research examining training progressions in key components within criterion COD tasks, such as spatial and temporal constraints, is required (Davids et al., 2006; Holmberg, 2009). Determining dose-response relationships specific training approaches have with

these context-dependent performance variables requires investigation with respect to sport and position.

- The relationships between strength, speed-strength and COD measures require further investigation across age, sex, sports, categories and positions. Future investigation of these should be driven by the constraints and determinants associated with general and position-specific COD tasks identified as representative (Davids et al., 2006; Holmberg, 2009) (Chapter 2).
- More research examining the relationship between time-rate force measures, such as impulse (FΔt), and performance in representative COD tasks is needed. More research examining the magnitudes and technical application of impulse during COD plant-step(s), and pre-plant-step and post-plant-step actions in representative COD tasks is needed. Identifying idiosyncratic impulse profiles will give insight that can assist in the planning and scheduling of training modes that influence two key factors in impulse expression – stretch rate and stretch load. These two neuromotor components can be modified via different training modes that impose variable conditions on contractile units, parallel and series elastic components, and neuronal networks involved in the movement (Ettema, 1996; Iacono et al., 2017; McBride et al., 2008; Serpell et al., 2014).

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APPENDICES

Appendix I. – Published Abstracts

Chapter 2 - Physical Characteristics and Performance in Change of Direction Tasks: A Brief Review and Training Considerations.

Abstract

Change of direction (COD) ability is considered to be critical for a number of sports, with respect to both assessment and training. This review examined factors that may influence performance in COD tasks, including underpinning physical qualities and physiological capabilities. A web-based search using PubMED, SPORTDiscus, ScienceDirect, and Google Scholar identified a total of 197 articles using the keywords *change of direction performance*, *change of direction ability*, *agility*, *pre-planned tasks*, *athletic performance*, and *multidirectional sprinting*. Due to the complexity and multifactorial nature of COD ability there is a need for both established assessment protocols and novel sport-specific measures. Examples of recommended established protocols are high-velocity entry COD tests such as the traditional or modified 505, the L-drill and the 45° sidestep. Examples of sport-specific measures are recording body positions and sprint time of an American football linebacker executing a 45° drop-back for curl-to-flat responsibility, or that of a badminton athlete executing multidirectional sprints from backhand rear court to forehand front court. Regarding training, it is appropriate to include strength and jump training with strength training prioritized to develop a foundation for unloaded and loaded jump training. Training to enhance COD capabilities should likely be incorporated during the phase where jump training is emphasized, and feature a progression from fundamental athletic maneuvers and sport-specific tasks observed during competition in the sport. Fundamental maneuvers include backpedaling, curvilinear sprinting, shuffling and multidirectional jumping. The progression to sport-specific training should include combining and sequencing maneuvers in a manner that replicates tasks executed at the respective position.

Keywords: Strength, jump ability, multidirectional sprint performance

Chapter 3 - The Relationship between Multidirectional Jumping and Performance in Change of Direction Tasks.

Abstract

This study investigated the test-retest reliability of two change of direction (COD; 180-degree and 45-degree COD sprints) and three multidirectional jump (MDJ) tests. Variables examined were approach time (sprint before plant-step), exit time (sprint after plant-step), total time (time to completion) and MDJ approach time and distance, respectively. Second, the ability of MDJ tests to predict performance in COD tests was examined. Twenty males (age: 27.5 ± 5.9 yr; height: 1.79 ± 0.1 m; body mass: 79.1 ± 12.0 kg) performed five trials for each assessment, executing left- (LT) and right-leg (RT) plant-steps, on two testing occasions separated by seven days. Between-session and within-session intraclass correlation coefficients (ICC) and coefficients of variation (CV) for all measurements were calculated. Usefulness of COD and MDJ tests was assessed via typical error and smallest worthwhile change (SWC) comparison. Results showed only one MDJ measurement generated unstable between-session reliability. Within-session reliability of approach and exit COD times, and MDJ approach times possessed confidence limits (90%CL) that extended below 0.75 ICC. All COD total times and MDJ distances presented high reliability (ICC 0.87 – 0.99) with low CV (0.9 – 4.1%). Right-leg MDJ distances were predictors of RT COD performances (r = 0.50 to 0.68, p = 0.001 to 0.024), while LT MDJ distances were predictors of LT180 COD performance (r = 0.67 to 0.71, p = 0.001). All measurements were useful in detecting SWC in performance. These findings suggest the COD tests and MDJ distances are reliable for assessing and monitoring COD performance in similar cohorts.

Chapter 6 - Effects of a Six-Week Strength Training Programme on Change of Direction Performance in Youth Team Sport Athletes.

Abstract

This study investigated the effects of eccentric phase-emphasis strength training (EPE) on unilateral strength and performance in 180- and 45-degree change of direction (COD) tasks in rugby union players. A 12-week cross-over design was used to compare the efficacy of resistance training executed with 3 s eccentric duration (EPE, n = 12) against conventional strength training, with no constraints on tempo (CON, n = 6). Players in each condition were categorised as 'fast' (FAST) or 'slow' (SLOW) using median trial times from baseline testing. Players recorded greater isometric strength improvements following EPE (ES = −0.54 to 1.80). Whilst these changes were not immediate, players improved in strength following cessation. Improvements in 180-degree COD performance was recorded at all test-points following EPE (ES = −1.32 to −0.15). Improvements in 45-degree COD performance were apparent for FAST following CON (ES = −0.96 to 0.10), but CON was deleterious for SLOW (ES = −0.60 to 1.53). Eccentric phase-emphasis strength training shows potential for sustained strength enhancement. Positive performance changes in COD tasks were category- and condition-specific. The data indicate the greatest improvement occurred at nine weeks following resistance training in these players. Performance benefits may also be specific to COD task, player category, and relative to emphasis on eccentric phase activity.

Keywords: isoinertial strength training; isometric strength; multidirectional speed; adolescent rugby athletes

Appendix II. Regression Equations.

Equation 1. LT180 Total = 203.760 + (-0.194)(LT1 distance).

Equation 2. LT180 Total = 187.958 + (-0.164)(LT15 distance).

Equation 3. LT180 Total = 203.068 + (-0.190)(LT25 distance.)

Equation 4. LT45 Total = 140.450 + (-0.163)(LT1 distance).

Equation 5. LT45 Total = 125.772 + (-0.135)(LT15 distance).

Equation 6. LT45 Total = 134.456 + (-0.150)(LT25 distance).

Equation 7. RT180 Total = 188.093 + (-0.168)(RT1 distance).

Equation 8. RT180 Total = 188.268 + (-0.167)(RT15 distance).

Equation 9. RT180 Total = 198.490 + (-0.184)(RT25 distance).

Equation 10. RT45 Total = 156.281 + (-0.196)(RT1 distance).

Equation 11. RT45 Total = 154.787 + (-0.191)(RT15 distance).

Equation 12. RT45 Total = 159.336 + (-0.198)(RT25 distance).

Appendix III. Ethics Approval for Chapters 3 – 7.

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

25 February 2016

Mike McGuigan
Faculty of Health and Environmental Sciences

Dear Mike

Re: Ethics Application: **15/322 The role of strength and power in change of direction performance in rugby.**

Thank you for your request for approval of an amendment to your ethics application.

I have approved the minor amendment to your ethics application allowing changes to the inclusion criteria.

I remind you that as part of the ethics approval process, you are required to submit the following to the Auckland University of Technology Ethics Committee (AUTEC):

- A brief annual progress report using form EA2, which is available online through http://www.aut.ac.nz/researchethics. When necessary this form may also be used to request an extension of the approval at least one month prior to its expiry on 30 September 2018;
- A brief report on the status of the project using form EA3, which is available online through http://www.aut.ac.nz/researchethics. This report is to be

submitted either when the approval expires on 30 September 2018 or on completion of the project.

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

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

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

All the very best with your research,

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

Cc: Frank Bourgeois fabourgeoisii@gmail.com, Nic Gill; Paul Gamble

Appendix IV. Participant Consent Forms.

Consent Form

Project title: **"The validity and reliability of a lateral jump task in relation to performance in 45° and 180° change of direction tasks"**

Project Supervisor: ***Mike McGuigan***

Researcher: ***Frank Bourgeois***

- ○ I have read and understood the information provided about this research project in the Information Sheet dated 25 August 2015.
- ○ I have had an opportunity to ask questions and to have them answered.
- ○ I am not suffering from any illness or injury that impairs my physical performance, or any psychological disorder that may impact on my ability to understand what is required of me during the research process.
- ○ I agree to have height and weight measurements recorded during all testing sessions, as well as participating in lower limb strength and power test measurements.
- ○ I understand that I am only required to participate in this study, and not required to do all of the stages of this research (studies 2-4).
- ○ I understand that I may withdraw myself or any information that I have provided for this project at any time prior to completion of data collection, without being disadvantaged in any way.
- ○ I agree to have a summary of my results given to my team coaches: (please tick one): Yes○ No○
- ○ I agree to take part in this research.
- ○ I wish to receive a copy of the report from the research (please tick one): Yes○ No○

Participant's signature: .....……

……

Participant's name: .....……

……

Participant's Contact Details (if appropriate):

Date:

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

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

Consent Form

Project title: **"The validity and reliability of a lateral jump task in relation to performance in 45° and 180° change of direction tasks"**

Project Supervisor: ***Mike McGuigan***

Researcher: ***Frank Bourgeois***

○ I have read and understood the information provided about this research project in the Information Sheet dated 25 August 2015.

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

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

○ If I withdraw, I understand that all relevant information will be destroyed.

○ I permit the researcher to use the videos that are part of this project, either complete or in part, alone or in conjunction with any wording and/or pictures solely and exclusively for (a) the researcher's evaluation; and (b) educational exhibition and examination purposes and related design works.

○ I agree to have a summary of my results made available to my team coaches: (please tick one): Yes○ No○

○ I agree to take part in this research.

Participant's signature: .....……

Participant's name: .....……

Participant's Contact Details (if appropriate):

Date:

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

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

Consent Form

Project title: **"The effects of 6-week eccentrically-emphasized dynamic strength training on performance in 45° and 180° change of direction tasks"**

Project Supervisor: ***Mike McGuigan***

Researcher: ***Frank Bourgeois***

- ○ I have read and understood the information provided about this research project in the Information Sheet dated 25 August 2015.
- ○ I have had an opportunity to ask questions and to have them answered.
- ○ I am not suffering from any illness or injury that impairs my physical performance, or any psychological disorder that may impact on my ability to understand what is required of me during the research process.
- ○ I agree to have height and weight measurements recorded during all testing sessions, as well as participating in lower limb strength and power test measurements.
- ○ I understand that I am only required to participate in this study, and not required to do all of the stages of this research (studies 1, 2 or 4).
- ○ I understand that I may withdraw myself or any information that I have provided for this project at any time prior to completion of data collection, without being disadvantaged in any way.
- ○ I agree to have a summary of my results given to my team coaches: (please tick one): Yes○ No○
- ○ I agree to take part in this research.
- ○ I wish to receive a copy of the report from the research (please tick one): Yes○ No○

Participant's signature: .....……
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Participant's name: .....……
……

Participant's Contact Details (if appropriate):

Date:

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

Consent and Release Form

Project title: **"The effects of 6-week eccentrically-emphasized dynamic strength training on performance in 45° and 180° change of direction tasks"**

Project Supervisor: ***Mike McGuigan***

Researcher: ***Frank Bourgeois***

- ○ I have read and understood the information provided about this research project in the Information Sheet dated 25 August 2015.
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- ○ I agree to have a summary of my results made available to my team coaches: (please tick one): Yes○ No○
- ○ I agree to take part in this research.

Participant's signature: .....……

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Participant's name: .....……

……

Participant's Contact Details (if appropriate):

Date:

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

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

Consent Form

Project title: **"The effects of 6-week unilateral multidirectional jump training on performance in 45° and 180° change of direction tasks"**

Project Supervisor: ***Mike McGuigan***

Researcher: ***Frank Bourgeois***

- ○ I have read and understood the information provided about this research project in the Information Sheet dated 25 August 2015.
- ○ I have had an opportunity to ask questions and to have them answered.
- ○ I am not suffering from any illness or injury that impairs my physical performance, or any psychological disorder that may impact on my ability to understand what is required of me during the research process.
- ○ I agree to have height and weight measurements recorded during all testing sessions, as well as participating in lower limb strength and power test measurements.
- ○ I understand that I am only required to participate in this study, and not required to do all of the stages of this research (studies 1-3).
- ○ I understand that I may withdraw myself or any information that I have provided for this project at any time prior to completion of data collection, without being disadvantaged in any way.
- ○ I agree to have a summary of my results given to my team coaches: (please tick one): Yes○ No○
- ○ I agree to take part in this research.
- ○ I wish to receive a copy of the report from the research (please tick one): Yes○ No○

Participant's signature: .....……

Participant's name: .....……
……

Participant's Contact Details (if appropriate):

Date:

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Consent and Release Form

Project title: **"The effects of 6-week unilateral multidirectional jump training on performance in 45° and 180° change of direction tasks"**

Project Supervisor: ***Mike McGuigan***

Researcher: ***Frank Bourgeois***

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

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

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○ I permit the researcher to use the videos that are part of this project, either complete or in part, alone or in conjunction with any wording and/or pictures solely and exclusively for (a) the researcher's evaluation; and (b) educational exhibition and examination purposes and related design works.

○ I agree to have a summary of my results made available to my team coaches: (please tick one): Yes○ No○

○ I agree to take part in this research.

Participant's signature: .....……

Participant's name: .....……

Participant's Contact Details (if appropriate):

Date:

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

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

Consent and Release Form

Project title: **"The relationship between isometric and isokinetic strength, jump ability, and performance in 45° and 180° change of direction tasks"**

Project Supervisor: ***Mike McGuigan***

Researcher: ***Frank Bourgeois***

- ○ I have read and understood the information provided about this research project in the Information Sheet dated 25 August 2015.
- ○ I have had an opportunity to ask questions and to have them answered.
- ○ I understand that I may withdraw myself, my image, or any other information that I have provided for this project at any time prior to completion of data collection, without being disadvantaged in any way.
- ○ If I withdraw, I understand that all relevant information will be destroyed.
- ○ I permit the researcher to use the videos that are part of this project, either complete or in part, alone or in conjunction with any wording and/or pictures solely and exclusively for (a) the researcher's evaluation; and (b) educational exhibition and examination purposes and related design works.
- ○ I agree to have a summary of my results made available to my team coaches: (please tick one): Yes○ No○
- ○ I agree to take part in this research.

Participant's signature: .....……

Participant's name: .....……

Participant's Contact Details (if appropriate):

Date:

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

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

Appendix V. Participant Information Sheets.

Participant Information Sheet (Chapters 3 and 4)

Date Information Sheet Produced:

25 August 2015

Project Title

The validity and reliability of a lateral jump task in relation to performance in 45° and 180° change of direction tasks

An Invitation

I, Frank Bourgeois, am a PhD student based at the Sports Performance Research Institute New Zealand at the AUT Millennium campus, School of Sport and Recreation, Faculty of Health and Environmental Sciences.

I would like to invite you to participate in a research study that will examine the validity and reliability of a single-leg jump task as a means for assessing performance in two change of direction tasks among New Zealand rugby union athletes. Your participation in this study is voluntary and you are free to withdraw at any time without consequence.

What is the purpose of this research?

The purpose of this research is to determine: (1) how well a single-leg jump task relates to change of direction performance; and (2) can the single-leg jump task be used to track changes in change of direction performance. This study will form a part of my proposed PhD.

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

You have been chosen as a potential participant in the study as you are a medically-cleared, active rugby union athlete who has a minimum of one year of organized strength training, and aged between 16 – 40 years.

What will happen in this research?

This research will require you to attend 2 familiarization session and 2 testing sessions. The 2 familiarization sessions will be separated by a minimum of 24 hours. The initial familiarization session will consist of measurement of body height, body weight, leg lengths, and perceived leg dominance.

During both familiarization sessions you will be required to do a double-leg horizontal jump, make ground contact with a single leg and immediately jump 45° to the opposite side, and land on two feet facing the new direction. Distances of the jump towards the force plate would be equal to three leg lengths with tape marking the start point. The centre of the force plate will be marked with tape designating the contact point for the single leg jump. The distance of the single-leg jump will be noted by measuring tape placed at a 45° angle from the approach jump, with the heel serving as the measurement point. You will be given 5 jump attempts on each leg at each leg length (total of 30 jumps). You will also be required to do 3 trials of both left- and right-oriented 505 and 45° sidestep, where the "plant step" will occur on an embedded force plate. Timing lights will be used to measure speeds of each trial.

Both testing sessions will be separated by a minimum of 7 days, and you will be asked to begin testing at the same time in each session. You will be given 5 jump attempts on each leg at each leg length, and 3 attempts in both left- and right-oriented 505 and 45° sidestep. The "plant step" will occur on an embedded force plate, and timing lights will be used to measure speeds of each attempt.

What are the discomforts and risks?

Due to the novelty of the task, you may feel fatigued upon completion and encounter some muscular soreness and discomfort. However, it will most likely be no greater than that experienced in your normal training regimen.

How will these discomforts and risks be alleviated?

You will have the opportunity to familiarize yourself with the testing procedure prior to maximal testing. You will also complete a thorough warm up to prepare you for these exercises. If at any point during the testing process you do not feel that you are able to proceed, inform the tester and the test will cease immediately. Finally, if you suffer an injury during the testing process or in the weeks leading up to testing that is likely to affect your performance or result in further injury please notify the tester at your earliest convenience.

What are the benefits?

The main benefit to you include gaining valuable knowledge about your change of direction and jump abilities which can be used to assist in future training. You will find out potential strengths and weaknesses concerning optimal jump distances, and leg dominance in jumping and change of direction tasks.

Secondly, not only will your participation assist me in completing my studies, your efforts will contribute to the scientific and practical knowledge concerning change of direction performance in rugby union athletes.

What compensation is available for injury or negligence?

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

How will my privacy be protected?

Your results will remain confidential and will only be shared with my supervisors (Mike McGuigan, Nic Gill and Paul Gamble) and you as a participant upon completion of the study.

What are the costs of participating in this research?

The familiarisation session will last approximately 120 minutes. Each testing session will last approximately 120 minutes. Therefore, the maximum amount of total time required for the 2 familiarisation and 2 testing sessions is expect to be no more than 8 hours. Petrol vouchers will be issued to cover the cost of traveling to SPRINZ, AUT Millennium.

What opportunity do I have to consider this invitation?

It would be helpful to the testers if you could indicate whether you wish to take part in this study within 2 weeks of receiving this information sheet.

How do I agree to participate in this research?

If you wish to take part in this study please contact Frank Bourgeois to arrange a time complete an informed consent form and submit a signed copy to him prior to testing.

If at any time after completing the informed consent form you do not wish to participate in this research, please notify Frank Bourgeois as soon as possible. You may withdraw at any point without prejudice.

Will I receive feedback on the results of this research?

Once all testing is completed you will receive a copy of your own results via email which you may then incorporate when planning your future training.

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

Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor, Prof. Mike McGuigan, *michael.mcguigan@aut.ac.nz*, or 921 9999 ext 7580

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

Whom do I contact for further information about this research?

Researcher Contact Details:

Frank Bourgeois – fabourgeoisii@gmail.com

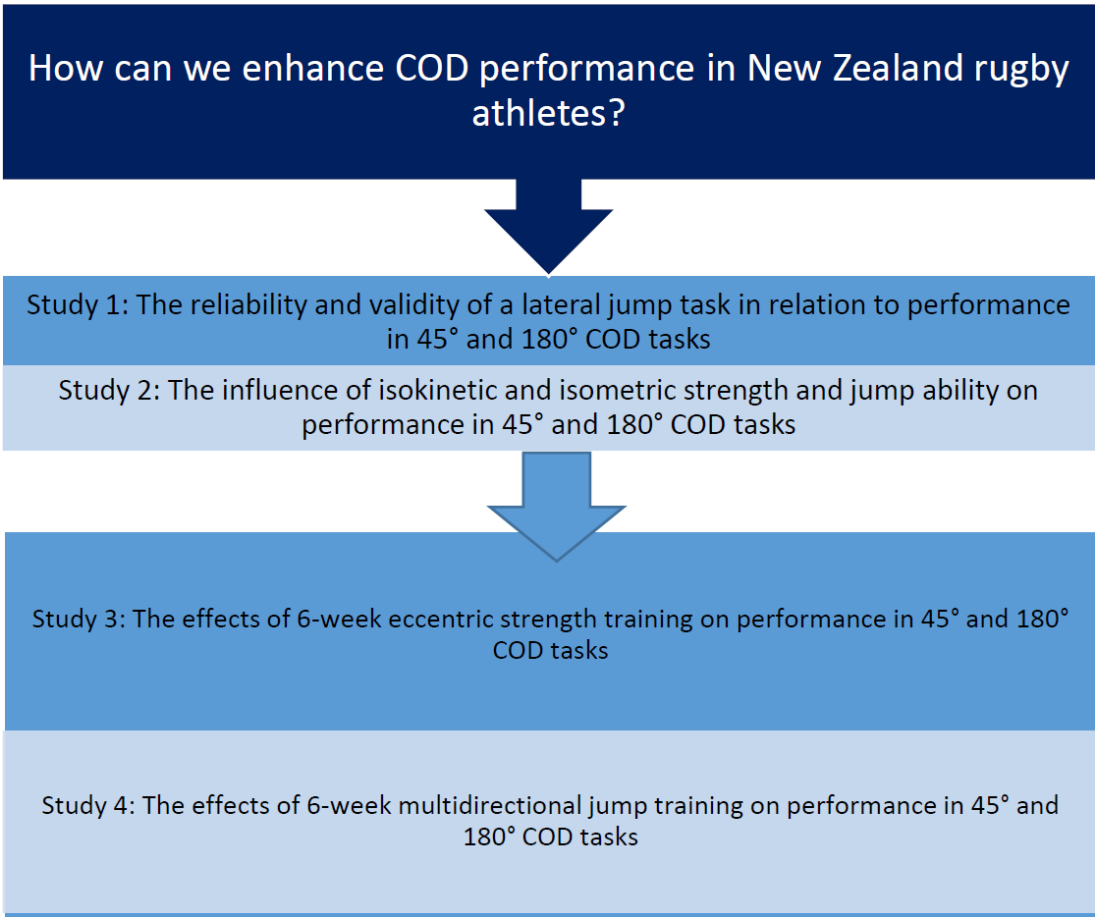
Mobile: 022 430 2236

Project Supervisor Contact Details:

Prof. Mike McGuigan – mike.mcguigan@aut.ac.nz

Tel: 921 9999 ext 7580

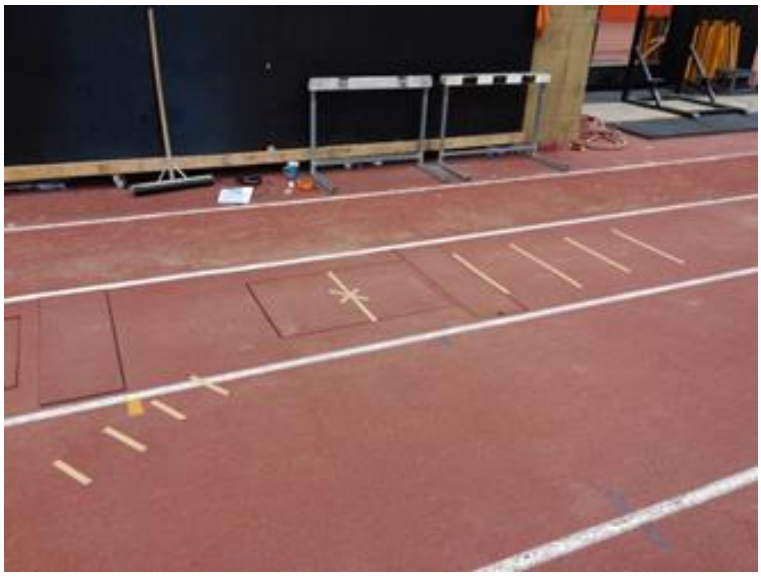
Flowchart of the stages



Illustrations of assessments

COD assessment

Jump assessment



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

Participant Information Sheet (Chapter 5)

Date Information Sheet Produced:

25 August 2015

Project Title

The relationship between isometric and isokinetic strength, jump ability, and performance in 45° and 180° change of direction tasks

An Invitation

I, Frank Bourgeois, am a PhD student based at the Sports Performance Research Institute New Zealand at the AUT Millennium campus, School of Sport and Recreation, Faculty of Health and Environmental Sciences.

I would like to invite you to participate in a research study that examines the relationship lower-body strength and power have with performance in change of direction tasks among New Zealand rugby union athletes. Your participation in this study is voluntary and you are free to withdraw at any time without consequence.

What is the purpose of this research?

The purpose of this study is to investigate: (1) how muscle function influences performance in 180˚ and 45˚ change of direction tasks; (2) single-leg strength and power profiles will be used to determine which performance variables are important in the assessment of performance in certain change of direction tasks relative to age, position and experience.

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

You have been chosen as a potential participant in the study as you are a medically-cleared, active rugby union athlete who has a minimum of one year of organized strength training, and aged between 16 – 40 years. This study will form a part of my proposed PhD.

What will happen in this research?

This research will require you to attend 2 testing sessions that will be separated by a minimum of 24 hours. All testing will be done prior to any scheduled training for that week, in addition to a 48 hour restriction of strenuous activity prior to test day. The session will begin with a standardized warm up

followed by familiarization attempts for each test and 3 maximal effort trials in a randomized order. Each assessment will be separated by approximately 5 min.

Day 1 will begin with the measurement of body height, body weight, leg lengths and leg dominance. Next, change of direction ability will be assessed with a 45° sidestep and the 505 tests, where three attempts to the left and right will be required. The "plant step" will occur on an embedded force plate and timing lights will be used to measure the speed of each trial. Following a 10 min rest and familiarization, you will be tested in vertical, horizontal and lateral countermovement jumps and 20 cm drop jumps. Each jump will be done on a portable force plate to record your force output. You will have 3 attempts per leg (24 total foot contacts and 42 total jumps) with approximately 30 s rest between each trial. Single-leg vertical, horizontal and lateral countermovement jumps will be done in a similar manner as the drop jumps with the exception of a box. For the vertical drop jump, when ready you will drop from the box and jump as high as possible and land on two feet. For the horizontal drop jump, when ready you will drop from the box, and jump forward as far as possible landing on two feet. For the lateral drop jump, you will drop from the box, and jump as far as possible to the opposite side, landing on two feet.

Day 2 will consist of three maximal strength assessments. Single-leg strength of the hip and knee will be measured via a Humac Norm dynamometer. Following familiarization you will be required to do single-leg extension and flexion in one orientation (e.g., seated knee assessment), followed by doing single-leg extension and flexion in the second orientation (e.g., supine hip assessment) for each leg. Five extensions and five flexions for the knee and hip with 2 min rest will be given between trials. Another strength test will be a single-leg back squat against an immovable bar over a force plate. You will perform three 5 s trials on each leg with 2 min rest between each trial. Lastly, you will perform a double-leg back squats in Exerbotics squat machine. You will execute a pre-programmed warm up trial (i.e., 50%) before undergoing two sequential maximal effort squats.

What are the discomforts and risks?

Due to the novelty of the task, you may feel fatigued upon completion and encounter some muscular soreness and discomfort. However, it will most likely be no greater than that experienced in your normal training regimen.

How will these discomforts and risks be alleviated?

You will have the opportunity to familiarize yourself with the testing procedure prior to maximal testing. You will also complete a thorough warm up to prepare you for these exercises. If at any points during the testing process you do not feel that you are able to proceed inform the tester and the test will cease immediately. Finally, if you suffer an injury during the testing process or in the weeks leading up to testing that is likely to affect your performance or result in further injury please notify the tester at your earliest convenience.

What are the benefits?

The main benefit to you include gaining valuable knowledge about your change of direction, jump and strength abilities which can be used to assist in future training. You will receive a comprehensive athletic assessment that investigates your strength-power profile and leg dominance. In addition you will know how the two relate to your performance in change of direction tasks.

Secondly, not only will your participation assist me in completing my studies, your efforts will contribute to the scientific and practical knowledge concerning change of direction performance in rugby union athletes.

What compensation is available for injury or negligence?

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

How will my privacy be protected?

Your results will remain confidential and will only be shared with my supervisors (Mike McGuigan, Nic Gill and Paul Gamble) and you as a participant upon completion of the study.

What are the costs of participating in this research?

Each test day will last approximately 90 min. Therefore the total time required for this study is approximately 3 hours. Petrol vouchers will be issued to cover the cost of traveling to SPRINZ, AUT Millennium. Also, Subway will be provided during both test days.

What opportunity do I have to consider this invitation?

It would be helpful to the testers if you could indicate whether you wish to take part in this study within 2 weeks of receiving this information sheet.

How do I agree to participate in this research?

If you wish to take part in this study please contact Frank Bourgeois to arrange a time complete an informed consent form and submit it to him prior to testing.

If at any time after completing the informed consent form you do not wish to participate in this research, please notify me as soon as possible. You may withdraw at any point without prejudice.

Will I receive feedback on the results of this research?

Once all testing is completed you will receive a copy of your own results via email which you may then incorporate when planning your future training.

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

Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor, Prof. Mike McGuigan, *michael.mcguigan@aut.ac.nz*, or 921 9999 ext 7580.

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

Whom do I contact for further information about this research?

Researcher Contact Details:

Frank Bourgeois – fabourgeoisii@gmail.com

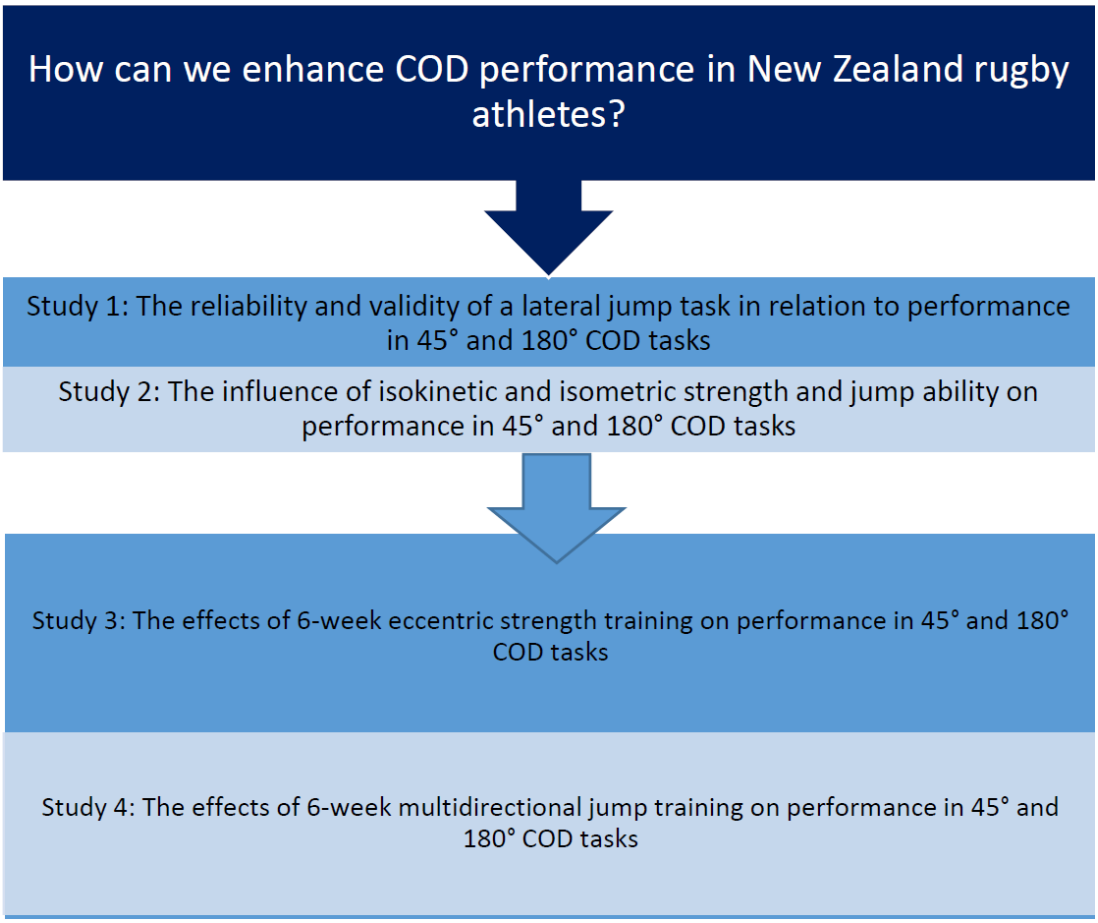
Mobile: 022 430 2236

Project Supervisor Contact Details:

Prof. Mike McGuigan – mike.mcguigan@aut.ac.nz

Tel: 921 9999 ext 7580

Flowchart of the stages



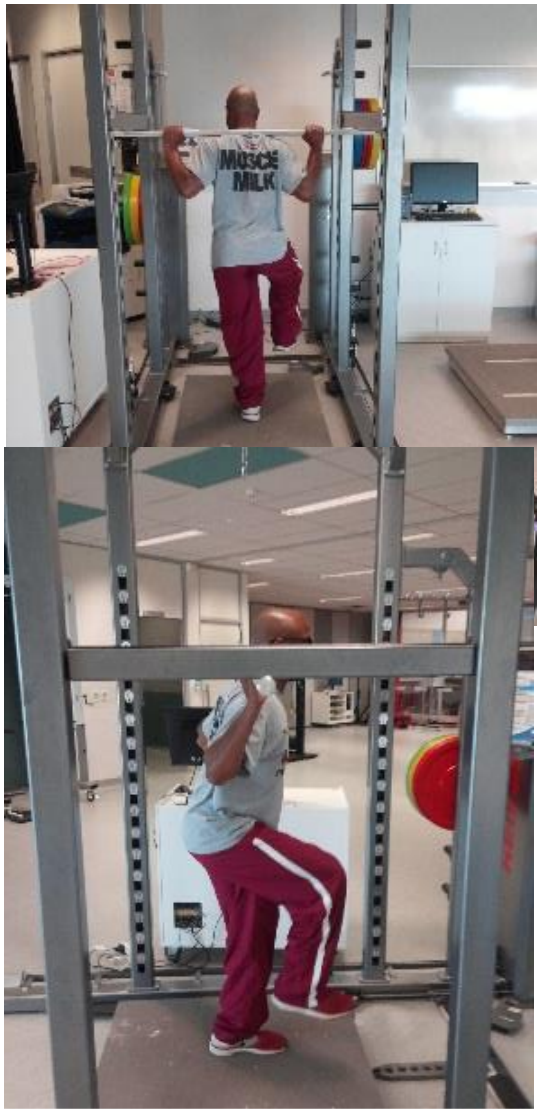
Illustrations of assessments

COD assessment

Jump assessment

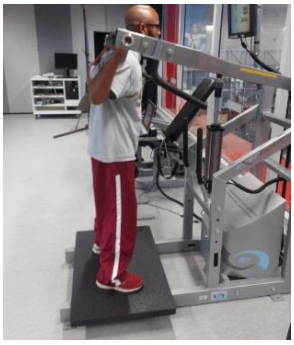
Strength assessments

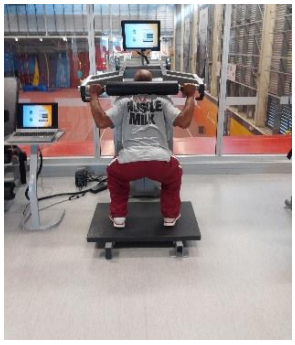
Unilateral isometric back squat test



Illustrations of assessments (con't)

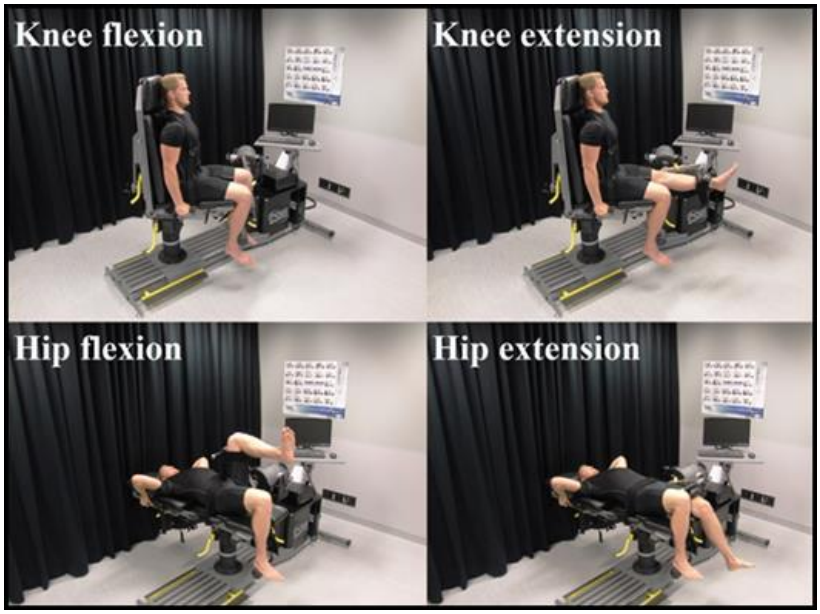
Bilateral isokinetic back squat





Power assessments

Unilateral isokinetic knee and hip extension



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Participant Information Sheet (Chapter 6)

Date Information Sheet Produced:

25 August 2015

Project Title

The effects of 6-week eccentrically-emphasized dynamic strength training on performance in 45° and 180° change of direction tasks

An Invitation

I, Frank Bourgeois, am a PhD student based at the Sports Performance Research Institute New Zealand at the AUT Millennium campus, School of Sport and Recreation, Faculty of Health and Environmental Sciences.

I would like to invite you to participate in a research study that examines the effect eccentric strength training has on performance in two change of direction tasks among New Zealand rugby union athletes. Your participation in this study is voluntary and you are free to withdraw at any time without consequence.

What is the purpose of this research?

The purpose of this study is to determine: (1) how effective eccentric strength training is in improving performance in two different change of direction tasks; and (2) is there a specific relationship between strength gains and type of change of direction task.

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

You have been chosen as a potential participant in the study as you are a healthy, active rugby union athlete who has a minimum of 1 year of organized strength training, and aged between 16 – 40 years.

What will happen in this research?

Pre- and post-testing will occur during weeks 0 and 8, respectively. Body measurements and leg preference will be collected before all pretest measures are taken. Following the standardized warm up you will be assessed in the 45° and 505 change of direction tests, where 3 trials of both left- and right-oriented tests will be done, with the “plant step”

occurring on an embedded force plate. Timing lights will be used to measure the speed of each trial. Lastly, double-leg strength will be measured via Exerbotics squat machine. You will execute a pre-programmed warm up trial (i.e., 50%) before undergoing two sequential maximal effort squats.

You will then be randomly placed in one of two groups: *eccentrically-emphasized back squat group*, or *drop landing group*. Each group will execute their respective intervention twice per week for 6 weeks, with sessions separated by a minimum of 24 hours. The *eccentrically-emphasized back squat condition* will involve controlling the descent time to 3 s via metronome during the back squat exercise. The *drop landing condition* will involve a progression with absolute loads (e.g., 10 kg plate) in the box drop exercise.

Again, your training will occur twice per week, with the *eccentrically-emphasized back squat* group executing 3 sets of load ≥ 85% 1-RM, and the *drop landing* group executing 3 sets of high intensity work. Training volume (load*sets*repetitions) will be used to ensure the work load of both groups is equal. Following each training session you will be asked to rate how hard their session was using a standardized scale (rating from 0-10).

During week 8 you will be retested identically to week 0.

What are the discomforts and risks?

Due to the novelty of the task, you may feel fatigued upon completion and encounter some muscular soreness and discomfort. However, it will most likely be no greater than that experienced in your normal training regimen.

How will these discomforts and risks be alleviated?

You will have the opportunity to familiarize yourself with the testing procedure prior to maximal testing. You will also complete a thorough warm up to prepare you for these exercises. If at any points during the testing process you do not feel that you are able to proceed inform the tester and the test will cease immediately. Finally, if you suffer an injury during the testing process or in the weeks leading up to testing that is likely to affect your performance or result in further injury please notify the tester at your earliest convenience.

What are the benefits?

The main benefit to you include gaining valuable knowledge about your strength capacities and how they relate to performance in two change of direction tasks. You will also be able to use this information to guide future programme development.

Secondly, not only will your participation assist me in completing my studies, your efforts will contribute to the scientific and practical knowledge concerning strength training and change of direction performance in rugby union athletes.

What compensation is available for injury or negligence?

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

How will my privacy be protected?

Your results will remain confidential and will only be shared with my supervisors (Mike McGuigan, Nic Gill and Paul Gamble) and you as a participant upon completion of the study.

What are the costs of participating in this research?

Each testing day will last approximately 90 min. The intervention of this study will be incorporated into your normal training regime requiring no additional time. Therefore, the total time required for this study outside of the 6-week intervention is approximately 3 hours. Petrol vouchers will be issued to cover the cost of traveling to SPRINZ, AUT Millennium, and Subway will be provided during both testing days.

What opportunity do I have to consider this invitation?

It would be helpful to the testers if you could indicate whether you wish to take part in this study within 2 weeks of receiving this information sheet.

How do I agree to participate in this research?

If you wish to take part in this study please contact Frank Bourgeois to arrange a time complete an informed consent form and submit it to him prior to testing.

If at any time after completing the informed consent form you do not wish to participate in this research, please notify me as soon as possible. You may withdraw at any point without prejudice.

Will I receive feedback on the results of this research?

Once all testing is completed you will receive a copy of your own results via email which you may then incorporate when planning your future training.

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

Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor, Prof. Mike McGuigan, *michael.mcguigan@aut.ac.nz*, or 921 9999 ext 7580

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

Whom do I contact for further information about this research?

Researcher Contact Details:

Frank Bourgeois – fabourgeoisii@gmail.com

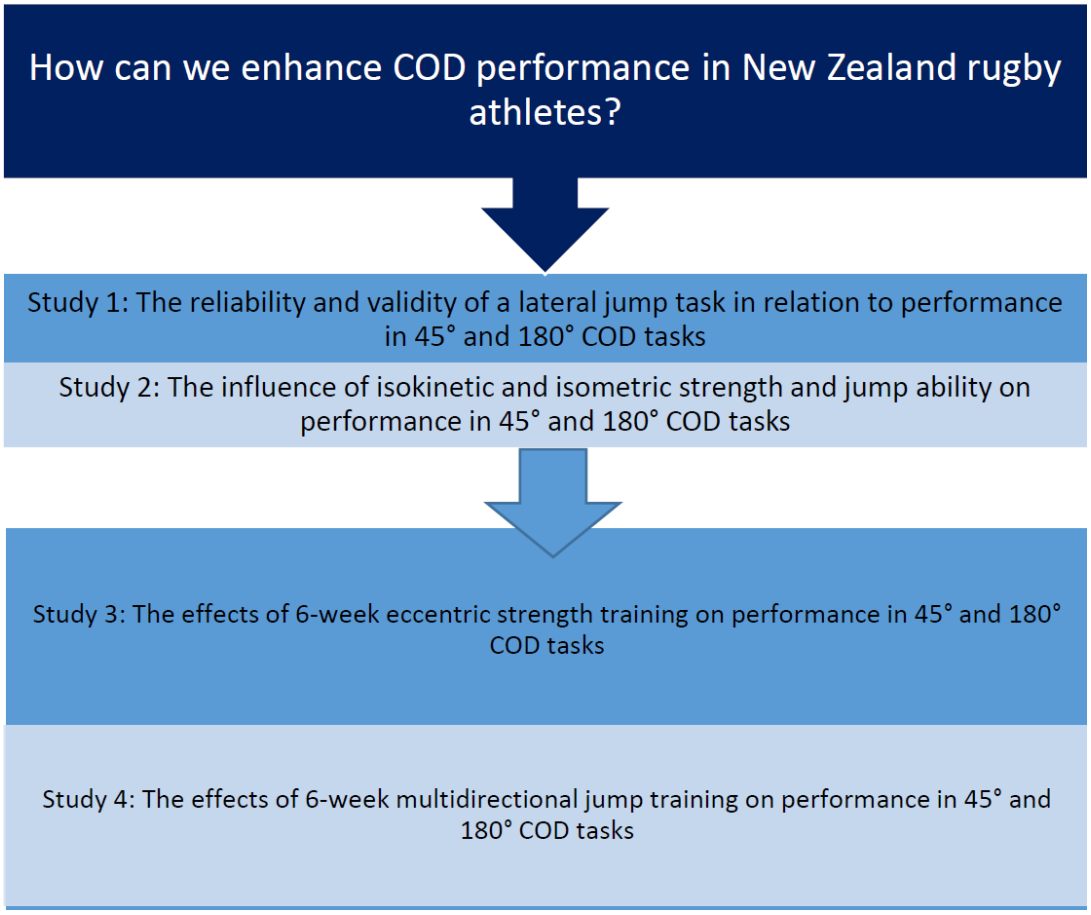
Mobile: 022 430 2236

Project Supervisor Contact Details:

Prof. Mike McGuigan – mike.mcguigan@aut.ac.nz

Tel: 921 9999 ext 7580

Flowchart of the stages



Illustrations of assessments

COD assessment

Strength assessments

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

Participant Information Sheet (Chapter 7)

Date Information Sheet Produced:

25 August 2015

Project Title

The effects of 6-week unilateral multidirectional jump training on performance in 45° and 180° change of direction tasks

An Invitation

I, Frank Bourgeois, am a PhD student based at the Sports Performance Research Institute New Zealand at the AUT Millennium campus, School of Sport and Recreation, Faculty of Health and Environmental Sciences.

I would like to invite you to participate in a research study that examines the effect multidirectional jump training has on performance in two change of direction tasks among New Zealand rugby union athletes. Your participation in this study is voluntary and you are free to withdraw at any time without consequence.

What is the purpose of this research?

The purpose of this study is to determine: (1) how effective jump training is in improving performance in two different change of direction tasks; (2) is there a specific relationship between jump enhancement and type of change of direction task; and (3) how do changes in strength about the hip and knee affect performance in specific change of direction tasks.

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

You have been chosen as a potential participant in the study as you are a medically-cleared, active rugby union athlete who has a minimum of 1 year of organized strength training, and aged between 16 – 40 years.

What will happen in this research?

Pre- and post-testing will occur during weeks 0 and 8, respectively. Body measures and leg preference will be collected before all pretest measures are taken. Following the standardized warm up you will be assessed in the 45° sidestep and 505 COD tests, where 3 trials of both left- and right-oriented tests will be

done, with the “plant step” will occur on an embedded force plate. Timing lights will be used to measure the speed of each trial. Next, single-leg jump performance will be assessed in vertical, horizontal and lateral jumping. A portable force plate will be used to measure ground reaction forces, and measuring tape will measure distances. Lastly, single-leg strength of the hip and knee will be measured via a Humac Norm dynamometer. Following familiarization you will be required to do single-leg extension and flexion in one orientation (e.g., seated knee assessment), followed by doing single-leg extension and flexion in the second orientation (e.g., supine hip assessment) for each leg. Each leg will be assessed during 5 extensions and 5 flexions for the knee and hip with 2 min rest will be given between trials.

Once pre-testing is completed you will be randomly placed in one of two groups: *vertical and horizontal jump group* or *vertical and lateral jump group*. Each experimental condition will include unilateral vertical jump training, though the second jump task will differ. The *vertical and horizontal jump group* will consist of horizontal jump training involving a vertical component prior to unilateral contact, while the *vertical and lateral jump group* will consist of lateral jumping with a horizontal component prior to unilateral contact.

To address the strength gains and familiarity common in training, intensity will be modified by either manipulating the system mass (i.e., medicine ball or dumbbells) or manipulating box height. Training volume (load*sets*repetitions) will be used to ensure the work load of both groups is equal. Following each training session you will be asked to rate how hard their session was using standardized scale (rated from 0-10). Training sessions will last approximately 1 hour, be done twice per week, and separated by a minimum of 24 hours.

During week 8 you will be retested identically to week 0.

What are the discomforts and risks?

Due to the novelty of the task, you may feel fatigued upon completion and encounter some muscular soreness and discomfort. However, it will most likely be no greater than that experienced in your normal training regimen.

How will these discomforts and risks be alleviated?

You will have the opportunity to familiarize yourself with the testing procedure prior to maximal testing. You will also complete a thorough warm up to prepare you for these exercises. If at any points during the testing process you do not feel that you are able to proceed inform the tester and the test will cease immediately. Finally, if you suffer an injury during the testing process or in the weeks leading up to testing that is likely to affect your performance or result in further injury please notify the tester at your earliest convenience.

What are the benefits?

The main benefit to you include gaining valuable knowledge about your strength capacities and how they relate to performance in two change of direction tasks. You will also be able to use this information to guide future programme development.

Secondly, not only will your participation assist me in completing my studies, your efforts will contribute to the scientific and practical knowledge concerning strength training and change of direction performance in rugby union athletes.

What compensation is available for injury or negligence?

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

How will my privacy be protected?

Your results will remain confidential and will only be shared with my supervisors (Mike McGuigan, Nic Gill and Paul Gamble) and you as a participant upon completion of the study.

What are the costs of participating in this research?

Each testing day will last approximately 120 min. Training sessions will last approximately 1 hour twice per week. Therefore, the total time required for this study is approximately 14 hours. Petrol vouchers will be issued to cover the cost of traveling to SPRINZ, AUT Millennium. Also, Subway will be provided during both testing days.

What opportunity do I have to consider this invitation?

It would be helpful to the testers if you could indicate whether you wish to take part in this study within 2 weeks of receiving this information sheet.

How do I agree to participate in this research?

If you wish to take part in this study please contact Frank Bourgeois to arrange a time complete an informed consent form and submit it to him prior to testing.

If at any time after completing the informed consent form you do not wish to participate in this research, please notify me as soon as possible. You may withdraw at any point without prejudice.

Will I receive feedback on the results of this research?

Once all testing is completed you will receive a copy of your own results via email which you may then incorporate when planning your future training.

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

Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor, Prof. Mike McGuigan, *michael.mcguigan@aut.ac.nz*, or 921 9999 ext 7580

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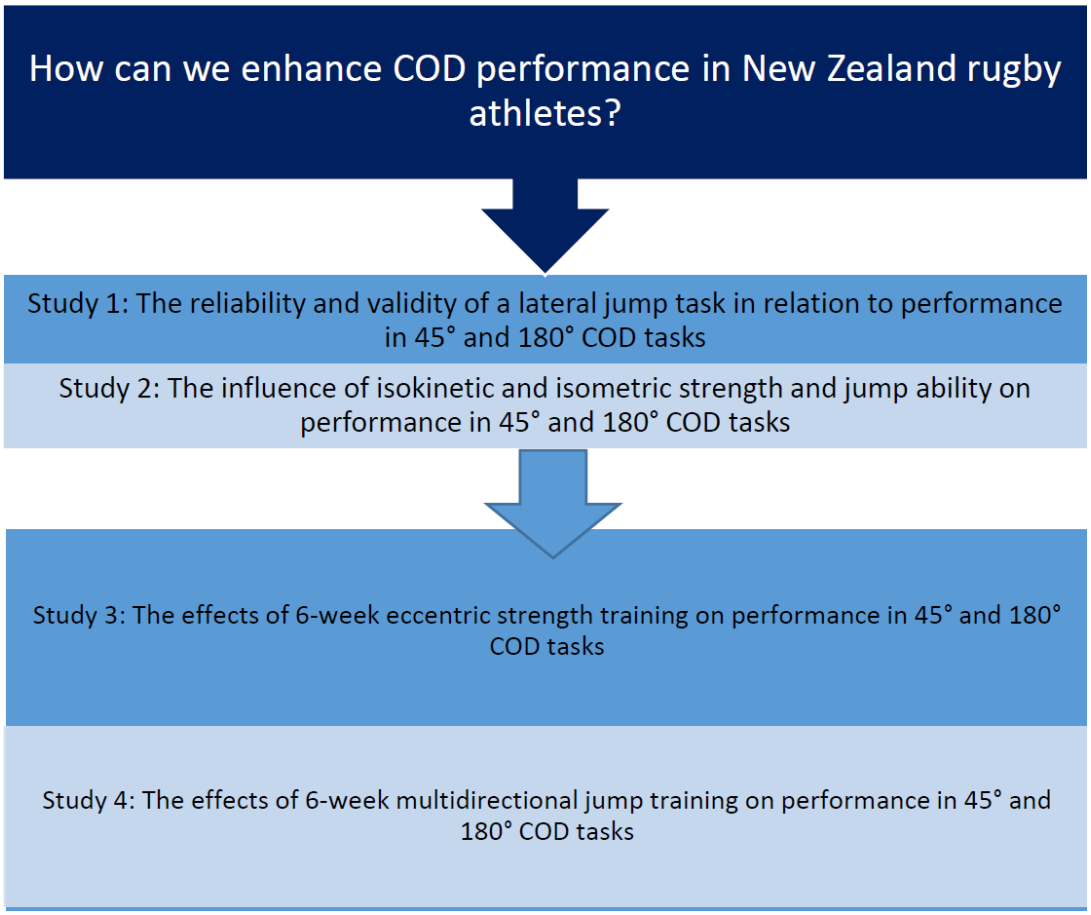
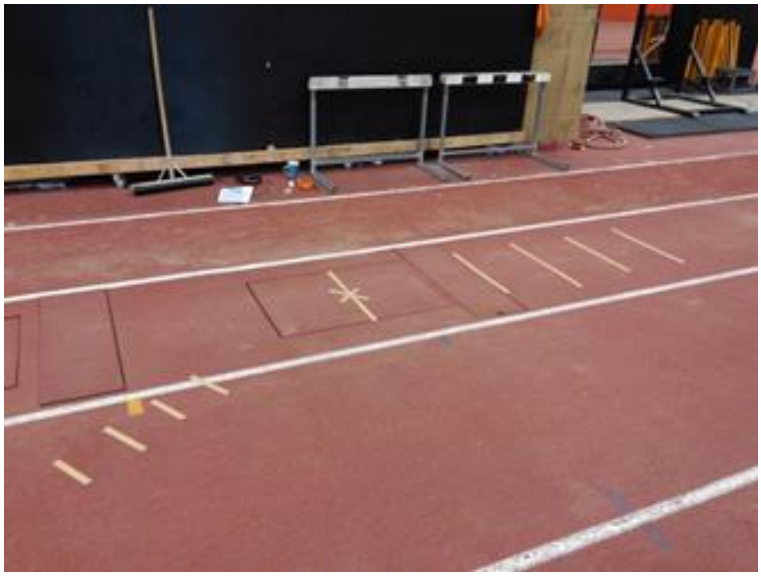
Flowchart of the stages



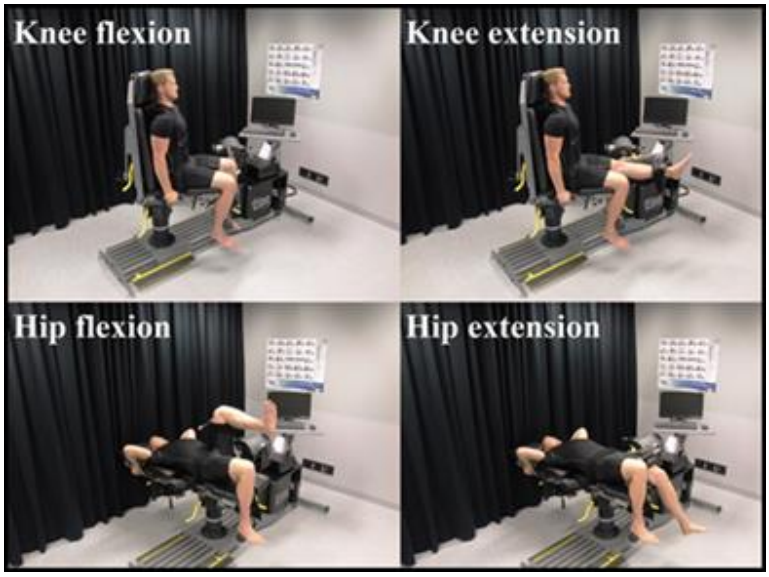
Illustrations of assessments

COD assessment

Jump assessment



Power assessments



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