



GRADUATE SCHOOL
EAST TENNESSEE STATE UNIVERSITY

East Tennessee State University
**Digital Commons @ East
Tennessee State University**

Electronic Theses and Dissertations

Student Works

8-2014

Lower Body Strength and Power Characteristics Influencing Change of Direction and Straight-Line Sprinting Performance in Division I Soccer Players: An Exploratory Study

Chieh-Ying Chiang
East Tennessee State University

Follow this and additional works at: <https://dc.etsu.edu/etd>

 Part of the [Sports Sciences Commons](#)

Recommended Citation

Chiang, Chieh-Ying, "Lower Body Strength and Power Characteristics Influencing Change of Direction and Straight-Line Sprinting Performance in Division I Soccer Players: An Exploratory Study" (2014). *Electronic Theses and Dissertations*. Paper 2406. <https://dc.etsu.edu/etd/2406>

This Dissertation - unrestricted is brought to you for free and open access by the Student Works at Digital Commons @ East Tennessee State University. It has been accepted for inclusion in Electronic Theses and Dissertations by an authorized administrator of Digital Commons @ East Tennessee State University. For more information, please contact digilib@etsu.edu.

Lower Body Strength and Power Characteristics Influencing Change of Direction and
Straight-Line Sprinting Performance in Division I Soccer Players: An Exploratory Study

A dissertation
presented to
the faculty of the Department of Exercise and Sport Sciences
East Tennessee State University

In partial fulfillment
of the requirement for the degree
Doctor of Philosophy in Sport Physiology and Performance
with a concentration in Sport Performance

by
Chieh-Ying Chiang
August 2014

Michael H. Stone, PhD, Committee Chair
Michael M. Ramsey, PhD, Committee Advisor
Kimitake Sato, PhD, Committee Advisor
G. Gregory Haff, PhD, Committee Advisor

Keywords: Soccer, Agility, Change of Direction, Strength, Power, Athlete's performance

ABSTRACT

Lower Body Strength and Power Characteristics Influencing Change of Direction and Straight-Line Sprinting Performance in Division I Soccer Players: An Exploratory Study

by

Chieh-Ying Chiang

The purpose of this dissertation was to investigate the influence of lower body strength characteristics on change of direction (COD) performance in NCAA Division I soccer athletes. Specifically, this dissertation served to examine: 1) whether the lower body strength and power were related to COD performance, 2) whether stronger athletes had superior COD performance than weaker athletes, 3) whether the force production asymmetry and strength dominant (SD) associated with COD performance, and 4) whether sex differences existed in kinetic variables during the stand phase of cutting.

The major findings of this dissertation include: 1) strength and power characteristics were moderately to strongly related to COD performance. Furthermore, soccer athletes' straight-line sprinting times were significantly related to COD performance outcomes. 2) Stronger athletes demonstrated the tendency to perform superiorly in modified 505 COD test when compared to weaker athletes. 3) Athletes who had more lower body force production asymmetry were more likely to perform asymmetrically during a COD test. However, the SD and the magnitude of asymmetry were not limiting factors for athletes' COD performance. 4) Male athletes demonstrated statistically significantly less COD total time, longer ground contact time (GCT), and better ability to apply forces and impulses while performing cutting. Based on the results, vertical forces and impulses during both the braking and propulsive phases of cutting ranged from 2.51 to 3.14 times larger than horizontal direction.

In summary, stronger and more powerful soccer athletes were able to perform in a superior manner for both the COD tasks and straight-line sprinting. This may be due to the ability to produce high force and power during the critical time periods. Although force production asymmetry during related to the asymmetrical performance during COD tasks, the SD and the magnitude of asymmetry did not limit the COD performance. Finally, statistical differences existed between sexes in kinetic variables during cutting may be due to the different approaches to apply force in this task. Moreover, the ability to generate higher force and impulse in the vertical direction could affect COD performance.

Copyright © 2014 by Chieh-Ying Chiang

All rights reserved

ACKNOWLEDGEMENTS

Dr. Stone and Coach Meg Stone, you are not only my dissertation advisors and my mentors, but also my family at ETSU. I cannot thank you enough for seeing my potential and accepting my application 3 years ago. The guidance and encouragement from you have dramatically changed my life. I am thankful for giving me such an amazing journey.

I would like to extend my gratitude to my dissertation committees (Dr. Sands, Dr. Sato, Dr. Haff, and Dr. Ramsey) for your time and efforts spent on this dissertation. Thank you for sharing your expertise in statistics, scientific method, and sport science with me.

I would also like to acknowledge Dr. Kimi Sato for your assistant and guidance, academically and personally. I cannot even imagine how terrible my life would be in the past 3 years if I did not meet you.

Dr. Chris Bailey, thank you for your personal and professional support throughout my PhD life. You are the best colleague and friend I have here in the US.

I am also grateful for ETSU Exercise and Sport Sciences Department and the Center of Excellence for Sport Science and Coach Education for letting me have opportunities to work as doctoral student/strength and conditioning coach and sport scientist. Specially thanks to men's and women's soccer teams, which allowed me to collect data for my dissertation and study those topics in which I am interested and passionate.

For my family, thank you for your unconditional love and support. And thank you for letting me to chase my dreams; even these dreams are thousands miles away from home.

Finally, I would like to express appreciation to my beautiful, supportive, and caring wife Miranda for her continued love, advice, and encouragement. Our life has been challenging us since we arrived here; it is not easy for us to deal with things that we never

had any experience in the past 27 years. We are proud of ourselves because we never give up, no matter how hard of those tasks were. Thank you, I could not have done it without you.

TABLE OF CONTENTS

	Page
ABSTRACT.....	2
LIST OF TABLES	9
LIST OF FIGURES	10
 Chapter	
1. INTRODUCTION	11
Statement of Purpose	15
Importance of the Study	16
Assumptions.....	17
Delimitations.....	18
2. REVIEW OF LITERATURE	19
Defining Agility and Change of Direction Ability (CODA)	19
Perceptual and Decision-Making Factors	22
Change of Direction Speed (CODS).....	23
Leg Strength and Power in COD Performance	24
Relationships with Leg Strength.....	25
Relationships with Leg Power	28
Relationships with Acceleration Sprint	32
Relationships with Unilateral Strength	33
Strength and Power Training Effects on CODA.....	34
Summary	37
3. EFFECTS OF STRENGTH AND POWER ON CHANGE OF DIRECTION AND STRAIGHT-LINE SPRINT PERFORMANCE IN DIVISION I SOCCER PLAYERS: AN EXPLORATORY STUDY	39
Abstract.....	40
Introduction.....	41
Methods	42
Results.....	48
Discussion	52
Practical Applications	56
Conclusion	57
References.....	58
4. BILATERAL ASYMMETRY DOES NOT EFFECT CHANGE OF DIRECTION PERFORMANCE IN COLLEGE SOCCER ATHLETES: AN EXPLORATORY STUDY	63
Abstract.....	64
Introduction.....	65
Methods	67
Results.....	70
Discussion	71
References.....	74
5. AN INVESTIGATION INTO KINETIC FACTOR COMPARISONS DURING A CHANGE OF DIRECTION TASK IN MALE AND FEMALE COLLEGE SOCCER PLAYERS: AN EXPLORATORY STUDY	77
Abstract.....	78
Introduction.....	79
Methods	80
Results.....	83

Chapter	Page
Discussion	89
References.....	92
6. SUMMARY	95
REFERENCES	97
Appendix A: ETSU Institutional Review Board Approval	113
Appendix B: ETSU Informed Consent Document	115
VITA	118

LIST OF TABLES

Table	Page
3.1 Test-retest reliability base on ICC and CV for COD and 10m-sprint variables	50
3.2 Relationships between COD and 10m-sprint performance.....	50
3.3 Relationships between IMTP, COD, and 10m-sprint performance	51
3.4 Relationship between vertical jump variables, COD, and 10m-sprint performance	51
3.5 Comparison of IPF _a and COD performance between the strong and weaker groups	52
4.1 The relationships between IMTP SI score and COD SI score	71
4.2 Comparison of COD performance between the SD and NSD sides.....	71
4.3 Comparison of COD performance between the more asymmetric group and less asymmetric groups	71
5.1 Test-retest reliability base on ICC and CV for COD total time, force and impulse variables	85
5.2 Descriptive statistics of athlete' age, height and body mass	85
5.3 Comparisons of sex differences in COD total time, force and impulse variables	86
5.4 Descriptive statistics of horizontal and vertical force and impulse variables	87

LIST OF FIGURES

Figure	Page
1.1 Universal agility determinants factors	16
3.1 Schematic approach of IMTP test set up	45
3.2 Schematic approach of COD test.....	46
4.1 Schematic approach of COD test.....	68
4.2 Dual force plate set up	69
4.3 IMTP test	69
5.1 Schematic approach of COD test set up	82
5.2 Comparison of ground contact time and COD test total time between male and female soccer athletes	87
5.3 Comparisons of force and impulse variable between sexes	88

CHAPTER 1

INTRODUCTION

Over the last few decades there have been a growing number of populations participating in soccer (Castillo-Rodríguez, Fernández-García, Chinchilla-Minguet, & Carnero, 2012; Kunz, 2007). Soccer has become one of the most popular sports in the world and is played by both sexes and different ages across all levels (Castillo-Rodríguez et al., 2012; Stølen, Chamari, Castagna, & Wisløff, 2005). It is most likely that big populations join soccer because minimal fitness levels and equipment are needed. However, in order to be successful at the elite level, a combination of technical, biomechanical, tactical, mental, and physiological ability is required (Hoff, 2005; Stølen et al., 2005). The physical components in soccer, such as muscular strength, power, sprint speed, and agility, have been given more attention by sport science and strength and conditioning fields (Chaouachi et al., 2012; Stølen et al., 2005). Therefore, determining the characteristics and assessments that are similar to an actual soccer match is critically important in order to develop appropriate training methodologies.

The physical contributes in elite level soccer athletes have been studied in recent research. Hoff (2005) observed that elite international soccer players could reach an average maximum oxygen consumption range from 55 to 68 ml · kg⁻¹ · min⁻¹ and a half-squat 1RM from 120 to 180 kg. Strong correlations between maximal strength, power, sprint, and jump abilities in soccer players are also reported by different authors (Castillo-Rodríguez et al., 2012; Chaouachi et al., 2012; Stølen et al., 2005; Wisløff, Castagna, Helgerud, Jones, & Hoff, 2004). Although the importance of physical capacities in soccer players, especially leg strength, has been studied by previous authors (Chamari et al., 2008; Peterson, Alvar, & Rhea, 2006; Vescovi & McGuigan, 2008), the interactions between strength characteristics

and other physical demands, for instance, agility and change of direction ability (CODA), remain unclear.

In order to better understand the physical and physiological aspects of soccer players, many authors have published studies to investigate specific movement patterns during soccer matches (Bloomfield, Polman, & O'Donoghue, 2007; Carling, Le Gall, & Dupont, 2012; Hoff, 2005; Spencer, Bishop, Dawson, & Goodman, 2005). One study by Bloomfield et al. (2007) provided extensive details of soccer-specific activities in the English Football Association (FA) Premier League matches. A computerized program was used to analyze movement patterns and traveling directions of 55 FA premier league soccer players, including standing, walking, jogging, sprinting, skipping, and shuffling. Players spent 48.7 ± 9.2 % of the time moving forward, performing the equivalent of 726 ± 203 turns during the match. Specifically, 609 ± 193 of these were turned from 0° to 90° to the left or right. Similar results also showed about 1,300 changes of movement patterns undertaken every 4 to 6 seconds under off-the-ball conditions (Stølen et al., 2005). Those time-motion analysis-type studies have revealed two significant movements features in a soccer game: change of direction (COD) and straight sprint.

Agility has been proposed as the ability to rapidly sprint and change direction while responding to outside stimuli (Sheppard & Young, 2006; Young & Farrow, 2006). Typically, agility movements in field sports (soccer, rugby) and court sports (basketball, volleyball) involve accelerating (short distance $<10\text{m}$), decelerating according to a stimulus (balls, opponents' defense, executing tactical strategies), and then changing to the new direction (Hewit, Cronin, & Hume, 2012c; Sheppard & Young, 2006; Spencer et al., 2005). Moreover, two major components of agility, change of direction speed (CODS) and perceptual, decision-making, have been proposed as key limiting factors for athletes' agility performance (Gabbett, Kelly, & Sheppard, 2008; Gabbett, Sheppard, Pritchard-Peschek, Leveritt, &

Aldred, 2008; Young, James, & Montgomery, 2002). Recently, the research object of agility studies has shifted to a topic that deals with the relation of athletes' decision-making process of sport-specific stimuli (Serpell, Youg, & Ford, 2011; Young & Farrow, 2013), also termed reactive agility (Gabbett, Kelly, et al., 2008; Oliver & Meyers, 2009; Young & Farrow, 2013; Young & Willey, 2010). A relative small number of studies have studied leg strength qualities and agility performance, especially using soccer athletes (Chaouachi et al., 2012; Vescovi & McGuigan, 2008).

Sprinting happens during a soccer match approximately every 70 seconds, each sprint lasting about 2 to 4 seconds (Stølen et al., 2005). Although the total distance covered by sprinting is only 1% to 11% of the total distance covered compared with other activities, straight sprinting is the most frequent scoring situation compared with other movement patterns (Faude, Koch, & Meyer, 2012). Faude and colleagues (2012) further showed that those scoring situations actually occurred during straight sprints that were followed by jumping and COD movements. From the existing literature, COD ability (CODA) and straight sprinting might play the crucial parts of physical components in a soccer match.

It is not uncommon to assess the associations between CODA and sprint performance in soccer. Reilly, Williams, Nevill, and Franks (2000) suggested that agility and sprint time were the best fitness characteristics for discriminating among young soccer players (elite versus subelite level). On the other hand, Spencer, Pyne, Santisteban, and Mujika (2011) also conducted a cross-sectional study and found a trivial to strong positive correlation between repeated sprint ability and agility among different ages (ages 11 to 17). Although the relationship between CODA and sprint performance seems strong, each one of them should be considered as an independent fitness feature (Little & Williams, 2005). Little and Williams (2005) examined 106 professional soccer players with a variety of sprint activities (10m acceleration, flying 20m sprint), of which agility (Zigzag) was also used to test the

contribution to soccer performance. The results showed that 10m acceleration, flying 20m sprint, and Zigzag agility were correlated to each other. However, the relatively low coefficient of determinations ($R^2=0.38, 0.11$ and 0.21 separately) indicated the essential distinct qualities between acceleration speed and agility.

The use of diverse muscular strength and power tests for team sport athletes has increasingly been the characteristics of study in sport science. Baker and Newton (2008) evaluated 40 national-level rugby players by testing lower body strength, power, acceleration, maximal speed, and agility. The results illustrated that 1RM squat strength and squat jump power could obviously differentiate first division and second division players. Cronin and Hansen (2005) also reported that the squat jump (SJ), countermovement jump (CMJ) height, and relative power output from SJ could be good predictors of variables for sprinting speed in professional rugby players. Similar findings were also reported by Barnes et al. (2007). Superior vertical jump heights were found in NCAA division I female volleyball players when compared to division II and division III levels. Furthermore, vertical jump height also related to basketball performance. Hoffman, Tenenbaum, Maresh, and Kraemer (1996) found that vertical jump height predicted playing time for division I basketball athletes. Additionally, vertical jump height was also associated with players' repeated sprint ability (RSA) (Stojanovic, Ostojic, Calleja-Gonzalez, Milosevic, & Mikic, 2012). Consequently, the ability to express optimized muscular strength and power is fundamental to athletes' success.

In summary, although a substantial number of studies have performed assessments on the critical fitness aspects that might affect team sport athletes' performance, information dealing with lower body strength characteristics, CODA and straight-line sprinting in collegiate soccer players is still critically lacking. The purpose of this study was to address these areas by shedding light on the underlying mechanisms.

Statement of Purpose

The primary purpose of this dissertation was to investigate the influence of lower body strength characteristics on CODA and straight-line sprint ability in NCAA Division I soccer athletes. Specifically, it was examined whether the lower body strength and power level contributed to the performance outcomes, such as COD speed and straight-line sprinting (acceleration of 0-5m, 5-10m, and 0-10m). Furthermore, the symmetry index (SI) scores during isometric mid-thigh pull (IMTP) and COD tasks (left and right) were calculated to determine if force production asymmetry affected the CODA.

The secondary purpose of this study was to examine whether sex differences existed in kinetic variables during a cutting maneuver. Moreover, forces and impulses from vertical and horizontal directions were analyzed to determine the dominance in COD test.

. In addition, specific aims of this study were to 1) Determine if stronger soccer athletes base on the IMTP test also performed better during a COD task and straight-line sprinting. 2) Determine whether athletes who possessed higher SI scores of IMTP also performed asymmetrically during COD test. 3) Determine whether the strength dominant (SD) side and bilateral strength asymmetry affected COD performance. 4) Determine whether sex differences existed in kinetic variables such as ground contact time (GCT), force, and impulse applied during the stand phase of cutting, and 5) which kinetic factors (vertical or horizontal) were dominant during the COD task.

Importance of the Study

Agility is one of the important physical attributes in soccer performance (Reilly, Williams, et al., 2000). In considering this issue, sport science and strength and conditioning related studies have attempted to define the limiting factors of agility performance (Barnes et al., 2007; Jones, Bampouras, & Marrin, 2009; Nimphius, McGuigan, & Newton, 2010; Young et al., 2002). Perceptual and decision-making factors and change of CODS have been proposed as two vital components under the universal agility components model (Sheppard & Young, 2006) (Figure 1. 1). However, the testing protocols for agility performance have not received a general consensus in the sport science community (Brughelli, Cronin, Levin, & Chaouachi, 2008).

There are a variety of tests described in the current literature. These tests required different energy systems (~1.65 to ~135 seconds) and the time of COD tasks range from 2 to 10 sec with primary vertical or horizontal force production (Brughelli et al., 2008). Considering soccer specific movement patterns, there has been relatively little research into the soccer specific agility tests, particularly CODA.

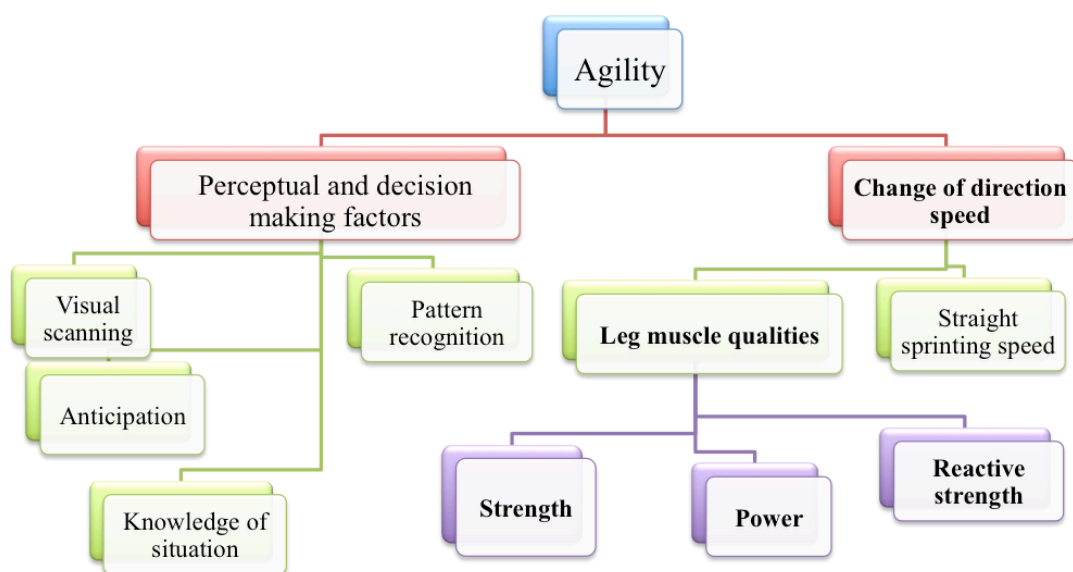


Figure 1.1. Universal agility determinants factors modified from Sheppard & Young (2006).

Recently investigators proposed the COD tests that are similar to soccer specific COD patterns (straight sprint with 90° to 180° COD), attempting to explain the relationship between strength and its derivatives and COD performance (Barnes et al., 2007; Castillo-Rodríguez et al., 2012; Jones et al., 2009; Nimphius, McGuigan, & Newton, 2012). To our knowledge, these are the only studies to examine the effect of lower body maximal strength and strength characteristics on COD performance.

Spiteri, Cochrane, Hart, Haff, and Nimphius (2013) divided subjects into stronger and weaker groups by measuring their single leg mid-thigh pull peak force (N kg^{-1}). The result indicated that the stronger group had better COD performance in terms of generating higher breaking force, propulsive force, breaking impulse and propulsive impulse. The stronger group also showed a faster post-COD stride time compared to the weaker group. However, the subjects in both the stronger and weaker groups were recreational athletes. Furthermore, the sports they participated in were not identical (soccer, basketball, and netball). It is hard to speculate whether the results could apply to other populations. Thus, this study will provide information about the effects of lower body strength and strength characteristics on straight-line sprinting and COD performance in NCAA Division I soccer athletes.

Assumptions

It is assumed that the characteristics of men and women soccer players in this study from East Tennessee State University (ETSU) represent the characteristics of collegiate soccer athletes at other mid-Division I NCAA institutions. It is also assumed that all participants were not affected by injuries and that all participants performed maximal effort during IMTP, straight-line sprinting, vertical jumps, and COD test.

Delimitations

Participants were limited to athletic populations who are participated and trained with men and women soccer teams as collegiate soccer players at ETSU. Participants were also limited to those who are familiar with Sport Performance Enhancement Consortium (SPEC) testing protocol, which consists of loaded and unloaded vertical jumps and IMTP tests to assess lower body strength and power characteristics. For this reason, testing reliability could be better ensured in order to investigate the relationships with COD tasks. All participants in this study had to be healthy and free from injury 6 months prior to the experiment.

CHAPTER 2

REVIEW OF LITERATURE

The content of this chapter is focused on the overview of current literature that deals with the relationships between athletes' lower body strength, power characteristics, and COD performance. First, the differences between agility and COD are defined. Two major components in agility performance including perceptual factors and decision-making and COD speed are briefly described. Second, physical and biomechanical features associated with COD in team sport athletes are introduced. Specifically, the factors related to muscle qualities and CODA, including lower body strength, jumping abilities, and acceleration ability are comprehensively discussed. This is followed by the outline of COD tests methodologies and training studies that focused on transfer effects from strength and power training to athletes' CODA.

Defining Agility and Change of Direction Ability (CODA)

Agility has been considered as one of the critical motor abilities for team sport athletes (Chaouachi et al., 2009; Gabbett, Sheppard, et al., 2008; Little & Williams, 2005; Sheppard & Young, 2006; Young, Benton, Duthie, & Pryor, 2001). Some authors have shown evidence that agility can be used as the most relevant physical capabilities for identifying talent in youth soccer players (Reilly, Bangsbo, & Franks, 2000; Reilly, Williams, et al., 2000).

Sheppard and Young (2006) have defined agility as “rapid whole body movement with change of velocity or direction in response to a stimulus” (p. 919). In the theoretical model they proposed, two of the primary components contributing to athletes' universal agility performance are: 1) perceptual factors and decision-making, which belongs to

cognition aspect and 2) CODS, which categorized as physical capacity (Sheppard & Young, 2006). More recently Spiteri et al. (2013) have described agility as the ability to perform reactive movements under either offensive or defensive conditions. In many team sports such as basketball, soccer, rugby, and Australian Rules football (ARF) agility plays a huge role in a game situation (Sheppard & Young, 2006). Those agility movements require athletes to perform intermitted high intensity activities including acceleration sprinting, deceleration stopping, and rapidly turning to a new direction (Baker & Newton, 2008; Hewit, Cronin, Button, & Hume, 2011; Hewit et al., 2012c; Spencer et al., 2005). In order to better understand the physiological and biomechanical characteristic features of agility, different authors have investigated the relationships between agility and athletes' physical capacities, which are broadly discussed in the following sections (Baker & Newton, 2008; Castagna et al., 2007; Gabbett, 2007; Gabbett, Kelly, et al., 2008; Lloyd et al., 2013; Oliver & Meyers, 2009; Spencer et al., 2005).

The common movement patterns involved in team sports usually contain certain distances (5-30m) of linear acceleration, followed by a deceleration prior to a change in direction (Hewit, Cronin, Button, & Hume, 2010; Hewit et al., 2011). Furthermore, athletes often move to a new direction based on reading the current position or the knowledge of the game under an offensive or defensive situation (Sheppard & Young, 2006; Spiteri, Nimphius, & Cochrane, 2012; Young & Farrow, 2006, 2013; Young et al., 2002). Therefore, the general idea of agility from recent literature has been referred as the ability to sprint with rapid change of directions while reacting to outside stimuli (Brughelli et al., 2008; Sheppard & Young, 2006; Young & Farrow, 2013; Young & Willey, 2010).

Although the term “agility” has been widely used in existing literature, the exact definition is still has not gained a consensus in sport science, sport medicine, and the strength and conditioning field (Salaj & Markovic, 2011; Sheppard & Young, 2006). For example,

terms have been used in literature, such as preplanned movement, predetermined movement, quickness, cutting maneuver, shuttle run, and reactive agility. These terms have also been used in scientific articles to refer to athletes' agility performance (Barnes et al., 2007; Brughelli et al., 2008; Cowley, Ford, Myer, Kernozek, & Hewett, 2006; Gabbett, Kelly, et al., 2008; Harris, Stone, O'Bryant, Proulx, & Johnson, 2000; McLean, Lipfert, & van den Bogert, 2004; Spiteri et al., 2012).

Thus, those movements that allow athletes to finish a change of direction task without processing a thought, and for which athletes apparently know the paths they will complete before performing it, have been defined as COD speed (CODS) or COD ability (CODA)(Oliver & Meyers, 2009). The majority of CODS and CODA tests are performed in comparatively closed environments so that participants have no need to react to outside stimuli when executing their tasks (Gabbett, Kelly, et al., 2008; Oliver & Meyers, 2009). The most common tests for evaluating CODS and CODA are the "L" run, T-test, Pro-agility test and Illinois agility run, in which athletes start the test from a stationary stance and accelerate then change direction in the horizontal plane (Brughelli et al., 2008; Gabbett, Kelly, et al., 2008; Oliver & Meyers, 2009) It has been suggested that the ability to express a high rate of force development and high power outputs are related to superior athleticism, such as jumping, sprinting, and COD performance in team sports athletes (Stone, Stone, & Sands, 2007). It is also not uncommon for strength and conditioning coaches to have a goal of helping their athletes pursue better neuromuscular strength and power performance. Consequently, the main focus of this study is to examine the interactions between muscle qualities, especially lower body strength and power characteristics, and COD performance.

Perceptual and Decision-Making Factors

Recently studies have attempted to examine the effects of cognition components on team sport athletes' agility performance (Gabbett & Benton, 2009; Gabbett, Kelly, et al., 2008; Scanlan, Humphries, Tucker, & Dalbo, 2013; Sheppard, Young, Doyle, Sheppard, & Newton, 2006; Young & Rogers, 2013). In considering perceptual and decision-making aspects in an athlete's agility performance, the first question that arises is whether these cognition factors impact agility performance or not. Previous studies have showed that the rate of processing a stimulus while changing direction could be a good tool to distinguish athletes' skill level. Athletes at higher levels tend to have faster reaction time and better agility performance (Gabbett, Kelly, et al., 2008; Lockie, Jeffriess, McGann, Callaghan, & Schultz, 2013; Oliver & Meyers, 2009; Sheppard et al., 2006). Gabbett, Kelly, et al. (2008) investigated the relationships between speed (5m, 10m, and 20m sprint), CODS (L run, 505 test, and modified 505 test) and reactive agility in 42 rugby players who were divided into two groups based on their skill level (first level, n=12; second level, n=30). The first level players showed a significantly faster movement time during the reactive agility test, which means better cognition to deal with outside stimuli compared to second level players. Sheppard et al. (2006) also reported the similar results of the AFL players.

More recently, a study was designed to ascertain if these perceptual, decision-making abilities are trainable (Young & Rogers, 2013). In this study, 25 elite U-18 AFL players were randomly assigned to either a change of direction group or a small-sided game group. The training session went over 7 weeks with 11 training sessions (15min/session). The small-sided game group showed significant improvement of total movement time, which was attributed to the reduction of the decision time of planned an AFL agility test and a video-base reactive agility test. This result did not happen to the change of direction group. Those

results also confirmed the points from Young and Farrow (2013) that athletes could improve reactive agility performance by training under sport-specific stimuli.

Change of Direction Speed (CODS)

Straight-line sprinting in soccer matches have been analyzed as the most frequent actions prior to a goal in both scoring and assisting players (Faude et al., 2012). In team sports many authors have categorized speed into acceleration speed, maximal sprint speed, and CODS (Castillo-Rodríguez et al., 2012; Kawamori, Nosaka, & Newton, 2013; Lockie, Murphy, Knight, & Janse de Jonge, 2011). Time-motion studies have showed that the typical sprint attended in a soccer match is less than 10m (Hoff & Helgerud, 2004). Therefore, it is reasonable to investigate the relationship between acceleration speed and CODS. It is also assumed that acceleration speed has common features with CODS due to the straight sprinting from initial static position (Jones et al., 2009; Nimphius et al., 2010; Peterson et al., 2006; Young et al., 2002). However, correlation studies have revealed inconsistent results. According to the results presented by Peterson et al. (2006) and Jones et al. (2009), straight sprint showed statistically negative correlations with COD tests ($r = -0.51-0.84$). Conversely, Young, McDowell, and Scarlett (2001) and Young et al. (2002) have been reported opposing results. Sheppard and Young (2006) stated that the inconsistent results might be contributed to different COD testing methods. In those studies with strong correlations, the COD tests usually contain one COD movement (Brughelli et al., 2008; Sheppard & Young, 2006). The more the directions change, the less shared variances between CODS and straight sprint (Little & Williams, 2005) and the less the transfer from straight sprint training to CODS as well (Sheppard & Young, 2006; Young, McDowell, et al., 2001).

As most studies attempted to test the relations between straight-line sprinting and CODS, the reacceleration phase after changing to a new direction may contribute to overall

COD performance. However, research on this issue is lacking. To our knowledge, only two studies have explored the relationships between muscular strength qualities and reacceleration ability. Castillo-Rodríguez et al. (2012) tested 45 physical education students with two COD tests, both of which covered 10m distances. Two turns (90° and 180°) after an initial 5m sprint was performed to present different COD tasks. Partial times were recorded to present the acceleration (first 5m) and reacceleration (second 5m) times. CMJ (bilateral and unilateral) and drop jump (30cm and 15cm) were also measured to evaluate the relations with COD tests. The results showed that all jumps had significant negative correlations with two CODS, specifically, the greater the jump height of CMJ and DJ, the less time spent when executing reacceleration. Moreover, Spiteri et al. (2013) reported statistical differences between stronger group and weaker groups on braking and propulsive impulse in COD tests. Subjects who performed above 50-percentile using IMTP were defined as stronger group, weaker group were those who performed below 50-percentile. The stronger group also showed faster post-COD strides speed than weaker group. Based upon these data muscular strength and power contribute to CODS, especially in the reacceleration phase. However, no existing study has identified which strength and power characteristics are related to CODS (both acceleration and reacceleration phases). More research is needed.

Leg Strength and Power in COD Performance

It has been proposed by Young et al. (2002) that muscle qualities such as leg strength, power, and reactive strength may be the decisive factors in athletes' CODA. Leg strength qualities also have been studied in relation to COD performance (Gabbett, Kelly, et al., 2008; Jones et al., 2009; Nimphius et al., 2012; Spiteri et al., 2013). Speed and CODS development are prominent features in many strength and conditioning programs. Strength and conditioning coaches and sport scientists often test and monitor athletes' leg strength and power regularly to analyze the relationships of those leg strength characteristics to speed and

CODA performance (Gonzalez et al., 2013; Gonzalez, Hoffman, Scallin-Perez, Stout, & Fragala, 2012). Therefore, it is worthwhile to determine which leg strength qualities are more relevant to CODA in team sports athletes. In this section leg strength characteristics that were tested by dynamic exercises, for example, 1RM and 3RM squat, in the isometric fashion, such as IMTP, isometric squat strength (ISOS), and by isokinetic devices are discussed. Leg power and its performance characteristics, which were tested via different vertical jumps, are also illustrated the relations with CODA. The topic of unilateral movement during COD (dominant and nondominant) and muscle power asymmetry is included in the last section.

Relationships with Leg Strength

Strength can be defined as the ability of a muscle or muscle groups to generate force (Bompa & Haff, 2009; Stone et al., 2007). Muscular strength has been related to sprint performance in many sports (Comfort, Haigh, & Matthews, 2012; Cunningham et al., 2013; Hori et al., 2008; McBride et al., 2009; Wisloff, Castagna, Helgerud, Jones, & Hoff, 2004). Strength is also vital for soccer performance (Hoff, 2005). Wisløff et al. (2004) reported very strong correlations between 1 RM half squat strength and 10m sprint ($r = -0.94$), 30m sprint ($r = -0.71$), 10m shuttle run ($r = -0.86$), and vertical jump height ($r = 0.87$) in national level soccer athletes. Similar results using squats have also been reported in national level softball players (Nimphius et al., 2010, 2012), American football (Harris et al., 2000), and rugby (Argus, Gill, & Keogh, 2012). Therefore, it is reasonable to examine the relationship between leg strength and CODA in team sports athletes.

Traditionally, 1 RM squat (absolute and relative) has been used as a tool for evaluating leg strength in field setting (Hori et al., 2008; Jones et al., 2009; Keiner, Sander, Wirth, & Schmidtbleicher, 2013; Moore & Fry, 2007; Nimphius et al., 2010). Many authors have reported the positive correlation between 1 RM squat and COD performance. Stone, Moir,

Glaister, and Sanders (2002) found that both absolute and relative 1RM parallel squat were strongly negatively correlated to badminton COD tests (single and multiple bouts) for national level badminton players ($r = -0.65$ to -0.79). Peterson et al. (2006) investigated 54 college athletes ($n = 19$ men and 36 women). The COD test showed the strong negative correlations with 1RM squat and 1RM squat $\cdot \text{kg body mass}^{-1}$ ($r = -0.784$ to -0.805). However, when comparing relative strength (1RM squat $\cdot \text{kg body mass}^{-1}$) and COD performance by sex, only female athletes showed a strong significant relationship (male = -0.33 , female = -0.63). This result may indicate the importance of absolute strength in COD performance, it may also indicate the greater strength is needed when athletes' body masses are heavier.

Nimphius et al. (2010) reported similar results. In this study three testing sessions took place pre, mid, and post a 20-weeks training period in 10 female softball players from the Australia national team. The 505 COD tests from dominant (D) and nondominant (ND) sides were measured to evaluate athletes' CODA. Interestingly, the statistical significant correlation between relative strength (1RM squat $\cdot \text{kg body mass}^{-1}$) and 505 COD tests only was displayed on the ND side ($r = -0.75$ to -0.85). The only statistical significance from the 505 D side were mid testing session ($r = -0.75$). The authors concluded that the superior results from ND sides could be speculated to relate to the weaker strength of the ND side. In addition, Hori et al. (2008) examined the relationships between 1RM front squat (FS), 1 RM hang power clean (HPC), and COD performance (505 test) in semiprofessional rugby players. Moderate negative significant correlations were reported between FS, HPC, and COD tests ($r = -0.41$ to -0.51). On the other hand, Markovic (2007) found a low negative correlation ($r = -0.17$ to -0.31) between an isoinertial squat (1RM) and three COD tests (side stepping, 20-yd shuttle run, and slalom run). However, the subjects from this study were physical education students ($n=76$), 14 of whom were varsity teams members. Although the authors stated that all of subjects had at least 1 year of resistance training experience, the

lower strength level and testing method (smith machine) may be questioned. In general, those studies provided the preliminary evidence that leg strength, especially 1RM squat (absolute and relative), was critical to COD performance. COD tests require subjects to rapidly accelerate from static positions and change to new directions in short distances. The ability to exert peak force dynamically may help to improve COD movements by overcoming the inertia during the change of a new direction.

Very few studies have examined the relationship between isometric strength and COD performance (Barnes et al., 2007; Spiteri et al., 2013). Barnes et al. (2007) measured volleyball players' leg strength via isometric squat (ISOS) test. Athletes from Division I (n= 9), Division II (n= 11), and Division III (n= 9) participated and represented different performance levels. The results showed a moderate negative correlation between ISOS peak force (PF) and COD test ($r = -0.37$). Another study by Spiteri et al. (2013) examined the relationship between athletes' CODA and leg strength via a more specific test. Twenty-four collegiate recreational athletes were divided into a stronger group and a weaker group. Stronger group was formed of those athletes who performed above 50 percentile using isometric strength test from the dominant side in respect to cutting direction. The COD test started with a straight sprint (6m) followed by one foot contacting with the force plate, cutting 45° and then athletes sprinting 2.5m to finish the test. Vertical and horizontal ground reaction forces (GRFs), impulse during braking and propulsive phases and kinematics variables were recorded to compare the group differences during a COD task. Interestingly, the stronger group revealed statistically significant differences for all testing variables except for approach velocity and total running time compared to weaker group. Further, the stronger group showed higher GRFs and impulse during braking and propulsive phases and demonstrated a faster post-COD stride. Those results showed that stronger people have superior ability to decelerate and reaccelerate during a COD task, which is vital to total COD

performance. The study was the first one to measure COD performance with a more precise method. Most studies that have failed to demonstrate strong relationships between strength and COD test may be due to the insensitive testing method in which total task times were the only variables to compare with different strength characteristics.

The measurements of leg strength via isokinetic dynamometers have been reported in COD studies (Chaouachi et al., 2009; Chaouachi et al., 2012; Jones et al., 2009; Young et al., 2002). Young et al. (2002) found low and nonstatistically significant relationships between unilateral and bilateral concentric power with straight sprints of different angles of change of directions (20°, 40°, 60° and 4 changes of direction of 60°, 2 to left and 2 to right). Only two variables showed statistical significance, which were bilateral power and single sprint with a change of 40° to the right. However, the findings from Chaouachi et al. (2012) showed the moderate relationships of strength on CODA ($R^2=0.45-0.48$), similar to the reports from Jones et al. (2009). The inconsistent results may be due to the subjects' background (elite soccer players and university students) and because of the different strength levels.

Furthermore, although the reliabilities of isokinetic strength tests have been reported in previous literature (Brown, Griffiths, Cronin, & Brughelli, 2013; Newton et al., 2006), the application from single-joint tests to multiple joints and complex tasks is doubtful (Stone et al., 2007). Future research should examine the relationship between leg strength and CODA with multiple joints tests.

Relationships with Leg Power

The ability to express high forces and high power outputs might be one of the most vital characteristics between winning and losing (Stone et al., 2007). The relationship between athletic movements and the capacity to produce high power outputs has been recognized in the sport science field (Haff & Nimphius, 2012; Stone et al., 2007). Research

has proved that powerful athletes tend to sprint faster (Cronin & Hansen, 2005; Hori et al., 2008; Peterson et al., 2006; Wisloff et al., 2004), jump higher (Barnes et al., 2007; Kraska et al., 2009; Stone et al., 2007), and perform better in different COD and repeated sprint tasks (Barnes et al., 2007; Hori et al., 2008; Nimphius et al., 2010; Spiteri et al., 2012; Stojanovic et al., 2012). Evidence has also been shown that powerful athletes are stronger than their weak counterparts (Cormie, McGuigan, & Newton, 2010; Kraska et al., 2009; Stone et al., 2007).

Furthermore, many researchers used vertical jumps as a key physical characteristic to identify athletes' performance across different sports, such as basketball (Chaouachi et al., 2009; Hoffman et al., 1996; Stojanovic et al., 2012), volleyball (Barnes et al., 2007), softball (Nimphius et al., 2010), rugby (Cronin & Hansen, 2005), soccer (Vescovi & McGuigan, 2008; Wisloff et al., 2004), American football (Harris et al., 2000), weightlifting (Stone et al., 2005), and track cycling (Stone et al., 2004). Hence, the vertical jump and its derivative variables often represent athletes' leg power performance in sport science related research. In this section, jump height (JH), CMJ, SJ, and drop jump (DJ) are reviewed, along with the associations with CODA from existing literature.

When examining the vertical jump height and CODA, athlete populations seemed to have superior interactions than nonathlete populations. Hori et al. (2008) investigated the relationship of 505 COD test and a variety of leg power performance in 29 semiprofessional ARF players. The significant relationship was observed between CMJ height (CMJH) and COD test ($r = -0.42$). Group differences (top and bottom 50% of 1RM hang power clean) of CMJH were also reported. Similar results were reported by Vescovi and McGuigan (2008). Female athletes from high school soccer ($n = 83$), college soccer ($n = 51$), and college lacrosse ($n = 79$) participated in this study. Moderate to large ($r = -0.47$ - -0.69) relationships between CMJH and COD tests were found. Additionally, two COD tests (Illinois and Pro-agility tests),

which were used in this study, shared many variances ($r^2 = 0.60$ in college soccer group), indicating one of these two COD tests may be appropriate to evaluate female athletes COD performance.

Barnes et al. (2007) examined the CMJH and shuttle COD test on a custom-made runway with a tri-axial AMTI force plate built in at the end. Athletes performed a sprint from the starting line, cutting on the force plate and turning 180° . After turning, athletes were required to sprint back to the starting line. Kinetics variables were collected using a force plate. Intriguingly, CMJH showed a statistically negative correlation with total task time (TT)($r = -0.58$), drop jump height (DJH)($r = 0.528$), reactive strength index (RSI, calculated by jump height/contact time) ($r = 0.545$) and vertical peak force (VPF) ($r = 0.421$). The authors concluded that the CMJH could be used as a predictor for athletes CODA. Jones et al. (2009) found a moderate negative correlation ($r = -0.498$) when evaluating CMJH and COD (505) test in 38 college students.

In contrast, Salaj and Markovic (2011) found weak negative correlations between CMJH and two COD tests (lateral stepping and figure 8 run)($r = -0.15$ to -0.24) in a group of college students. However, moderate to strong negative correlations ($r = -0.49$ to -0.59) between CMJH (bilateral and unilateral) and COD (TT of a 5-5 COD test) performance were found in college physical education students (Castillo-Rodríguez et al., 2012). CMJH (both leg, left and right side) and DJH (15 and 30cm) were used to examine the relationships between leg power and COD tasks. Although the DJH (both 15 and 30cm) showed significant relationships with the COD test, a regression analysis found CMJH (right side) was the best predictors for COD performance (adjusted $R^2=0.46$). In order to determine the interactions between vertical jump height and COD performance, more research is needed.

Additionally, peak power (PP)(W) from CMJ and SJ has shown a connection with COD performance. Peterson et al. (2006) found a strong negative correlation ($r = -0.73$) between COD test and PP using a jump and reach test, PP was calculated using the equation established by Sayers, Harackiewicz, Harman, Frykman, and Rosenstein (1999); however, the associations were weak when compared by sex (male= -0.03, female= -0.21). On the other hand, Hori et al. (2008) investigated the effects of absolute PP and relative PP (Watts divided by subjects' body mass) during CMJ under loaded (40kg bar) and unloaded conditioning. Both CMJ PP and relative CMJ PP showed significant correlations with the COD test. More recently Nimphius et al. (2010) have found results similar to those reported in previous study. PP from the Jump Squat (JS) with the following loadings: body mass (J_{BM}), BM+Bar (24.5kg)(J_{Bar}), BM+40% of 1RM (J_{40}), BM+60% of 1RM (J_{60}), BM+80% of 1RM (J_{80}) were used to evaluate the relationships with COD (505) test during pre-, mid-, and posttests of a 20-week training period. Interestingly, all JS PP showed no relation to COD (both ND and D) at pretest, however, strongly negative correlations revealed at mid-test ($r = -0.66$ to -0.90). Only ND side COD test showed significant correlations with JS PP at posttest ($r = -0.76$ to -0.85). Despite the insufficient evidence from the above studies, it appears that both PP and PP/BM from CMJ and JS may impact COD performance. Those results also indicated that athletes needed to apply greater forces during COD movements, which were similar to eccentric forces generated during CMJ and JS with different loading conditions. More research is necessary in order to better explain the relationships between COD and leg power characteristics.

Relationships with Acceleration Sprint

Traditionally strength and conditioning professionals tend to believe there is a strong relationship between athletes' sprinting performance and CODA and training athletes' sprinting ability could transfer to their CODA as well (Brughelli et al., 2008; Sheppard & Young, 2006). However, there is a lack of research to confirm this statement. Based on the results presented by Young, McDowell, et al. (2001), straight sprint training could not transfer its training effect to COD performance, the more directions to change, the less the transfer of training from sprinting ability. Little and Williams (2005) also stated that straight sprint and COD are distinctive physical abilities due to the small shared variances ($r^2=0.11$). Nevertheless, the results are not entirely clear.

More recently many authors have measured the acceleration ability in team sport athletes in order to answer more specific questions about the interactions between CODA and straight sprinting (Baker & Newton, 2008; Chaouachi et al., 2012; Condello, Minganti, et al., 2013; Condello, Schultz, & Tessitore, 2013; Scanlan et al., 2013; Vescovi & McGuigan, 2008). In terms of acceleration ability, time spent between 0-20m has been proposed as a valid value to measure (Young et al., 2008). Vescovi and McGuigan (2008) reported moderate to large positive relationships ($r = 0.30$ to 0.67) between 9.1m sprint time and two COD tests (Illinois and slalom tests). The results were even stronger when comparing flying 9.1m and COD tests ($r = 0.58$ to 0.77). Moreover, Condello, Minganti, et al. (2013) tested 157 youth rugby players (age range 8-19y) with 15m straight-line sprinting (15SS) and 15m COD test (15COD). The results from this study showed a strong positive correlation between 15SS and 15 COD in each age group ($r = 0.55$ to 0.90) and the pooled sample ($r = 0.75$). Other studies also revealed similar results (Condello, Schultz, et al., 2013; Jones et al., 2009; Nimphius et al., 2010; Peterson et al., 2006). The conflicts resulting from previous studies are most likely due to 1) the sprinting distance, as the relationships decreased when athletes were

required to sprint longer distances and 2) different testing protocol, as the complexity of COD tests increased, less associations were showed between straight sprint and CODA.

Relationships with Unilateral Strength

Asymmetry in sports, such as range of motion, flexibility, limb length, weight distribution, and force production, has been gaining interest (Bailey, Sato, Alexander, Chiang, & Stone, 2013; Hewit, Cronin, & Hume, 2012a, 2012b; Hoffman, Ratamess, Klatt, Faigenbaum, & kang, 2007; Impellizzeri, Rampinini, Maffiuletti, & Marcora, 2007; Sato & Heise, 2012). More recently the topic of the unilateral strength and COD performance also has drawn investigators' attention (Chaouachi et al., 2012; Henry, Dawson, Lay, & Young, 2013; Hoffman et al., 2007; Young et al., 2002). Young et al. (2002) sought to determine the relationships between concentric power, reactive strength and sprints with change of direction at different angles (20°, 40°, 60° and four changes of direction of 60°, two to left and two to right). It was assumed that unilateral strength and power may impact CODS due to the single leg lateral push-off during turning. Male athletes (n=15) from club level participated in this study. Unilateral power outputs from left and right sides were measured using an isokinetic dynamometer knee extension at a set of speed of 40°. sec⁻¹. Reactive strength from both sides was examined by a drop jump test. The reactive strength score was calculated as jump height (cm)/contact time (sec). No significant correlations were found between unilateral power outputs and COD tests; some moderate and statistically significant coefficients were found between the right side reactive strength score and COD tests. It was concluded that the participants who turned faster on one side tended to have a higher reactive strength performance. The other study by Hoffman et al. (2007) found a statistically significant difference of unilateral jump power outputs between D and ND sides. However, the power deficit between N and ND (9.7±6.9%) did not relate to COD performance. Future research should focus on investigating the effects of leg strength symmetry during COD tests.

Strength and Power Training Effects on CODA

There are a few of studies that have examined the positive transfer effects of strength and power training on COD performance (Harris et al., 2000; Keiner et al., 2013; McBride, Triplett-McBride, Davie, & Newton, 2002; Miller, Herniman, Ricard, Cheatham, & Michael, 2006; Moore & Fry, 2007; Nimphius et al., 2010, 2012). However, some studies have failed to show the CODA improvement from strength and power training (Brughelli et al., 2008; Jullien et al., 2008; Tricoli, Lamas, Carnevale, & Ugrinowitsch, 2005). Interestingly, some authors have also reported mixed results (Harris et al., 2000; Moore & Fry, 2007).

To our knowledge, there is only one study that has examined the long-term strength training effect and soccer players' COD performance. In this study Keiner et al. (2013) evaluated the relationships between the 1RM squat \cdot body weight⁻¹ (SREL) in the back squat and front squat and COD performance. In this study 112 male soccer players were recruited and divided into a strength-training group (STG) and a second group (CG). The STG group went through approximately 2 years of soccer training with two strength training sessions per week. The CG group only participated in regular soccer practices. Subgroups from those two groups were also categorized (A= under 19 years old, B= under 17 years old, C= under 15 years old) in order to compare the training effect on different maturation levels. Results showed that the additional strength training over 2 years significantly affected players' COD performance. All subgroups from the STG group showed a significantly faster COD time compared to CG. A moderate to high negative correlation between the COD test and SREL was also revealed. The authors concluded that transfer effects from long-term periodized strength training positively improve soccer players' speed-strength during COD tasks.

Similarly, Nimphius et al. (2012) found the CODA improvement after 14 weeks of periodized resistance training (RT) intervention. Ten softball female athletes from the

Australian national team participated in this study. Muscle architecture, 1RM squat, 1 RM squat $\cdot \text{BM}^{-1}$ (kg), first and second bases sprint time, and D and ND sides of 505 COD tests were measured. The RT was executed in two to three sessions in conjunction with the regular skill-training sessions. After 14 weeks of RT training, significantly different results showed on all testing variables, except for the 505 ND and first sprint. Large to very large relationships in percent changes of relative squat strength (squat 1 RM $\cdot \text{BM}^{-1}$) were demonstrated on 505 ND ($r = -0.51$) and 505 D ($r = -0.70$). The authors explained that the nonsignificant results of 505 ND after RT training might be related to athletes' weak sides, also commonly reported in softball (Newton et al., 2006; Nimphius et al., 2010).

In addition, 8 weeks of jump squat training also showed the improvement of the COD performance (McBride et al., 2002). Subjects with 2 to 4 years of resistance training experienced were divided into a heavy-load jump group (80% of 1 RM) and a light-load jump group (30% of 1 RM). Significantly decreased COD time was reported on both group after training period. This study showed the potential beneficial transfer effects from training vertical movements (applying vertical force of jump squat) to horizontal movements (t-test). Similar training effects were also reported by Miller et al. (2006). The subjects went through 6 weeks of unilateral and bilateral jumps training in both vertical and horizontal direction. The results displayed a statistically significant decreased of the T-test and the Illinois agility test time. From those two studies, a higher eccentric strength would be required when subjects squat down to the bottom position, which might mimic the braking phase during COD movements (Glaister, Orendurff, Schoen, Bernatz, & Klute, 2008; Haff & Nimphius, 2012; Miller et al., 2006; Spiteri et al., 2013).

Additionally, there are two training studies that have reported intriguing results. Harris et al. (2000) investigated periodized weight training effects on Division I football players. Athletes were assigned to a high force group (HF; $n=13$, 80%-85% of 1RM value), a

high power group (HP; n=16, relative intensity about 30% of peak isometric force) and a combination group (COM; n= 13), each group trained 4 days per week for 9 weeks. Prior to the training, all of three groups went over an identical 4 weeks period of high volume weight training (sets of 10 repetitions); a 10-yard shuttle run was employed to evaluate athletes' CODA. Only COM showed the significant decreasing of 10-yard shuttle run (7%) compared to HF and HP. The authors suggested the training adaptation might be from training both neural and elastic components and muscle contraction speed. One must consider that a possible factor that influences athletes' COD performance is the summation total training stress. Moore and Fry (2007) examined performance and hormonal response changes after 15 weeks of football off-season training period in Division I level athletes. Performance and hormonal variables were evaluated prior to training (T1). And the first 4-weeks of weight training (T2), following by 5 weeks of a combination of weight training and high volume conditioning that included a series of COD drills (T3). Theoretically, we would expect COD performance to be better after training with specific COD drills. Surprisingly, the COD performance, 1RM squat and 1RM power clean significantly improved at T2 without any COD drills intervention. However, the COD performance that was tested by a 20-yd pro-agility test did not progress at T3. Furthermore, the serum testosterone level significantly decreased. Furthermore, both 1RM squat and 1RM power clean reached a significant decreased at T3. The results indicated the importance of total training volume that directly affects COD performance. Too much training volume could cause the dramatic decreasing of CODA. The results also showed the inverse relationship between serum testosterone level and strength performance (1RM squat and 1RM power clean), indicating too much training volume may impair athletes' strength development. Therefore, combining high eccentric force training and periodized weight training that smartly manipulated training volume might improve athletes' COD performance. More longitudinal research is needed.

The inconsistent results from previous studies could be speculated as the combination of complex factors, for example, length of training period (short term versus long term), training age and status of subjects (physical education students versus athletes populations), training modalities (machines versus free weights; plyometric versus weightlifting movements), testing methods (agility versus CODA). Therefore, more research is needed to clarify the strength and power training effects on COD performance.

Summary

Agility has been considered as one of the essential components to athletes' success, especially for team sport athletes (Gabbett, Kelly, et al., 2008; Reilly, Bangsbo, et al., 2000). However, most studies have failed to approach the appropriate term describing the differences between agility and CODA. Many authors have defined agility as the ability to rapidly change directions with minimal loss of movement speed while responding to the outside stimuli (Sheppard & Young, 2006; Young & Farrow, 2013). This ability is particularly crucial for team sport athletes to evade or gain positional leads during game situations (Chaouachi et al., 2012; Green, Blake, & Caulfield, 2011b). On the other hand, preplanned movements with quick changes of directions also called CODA, which plays an equally important role in game environments (Nimphius et al., 2010; Spiteri et al., 2013). In this study CODA is specifically defined as the ability to accelerate from a standing position, decelerate and reaccelerate followed by changing to new direction without reacting to outside stimuli.

Although improving athletes' lower body strength and power performance are the main goals in most strength and conditioning programs, very few studies have evaluated the transfer effects from strength and power training to CODA. Inconsistent results from

previous studies might be explained from the diverse testing methods, subjects' background, training modalities, and the length of training intervention.

The relationships between CODA and lower body muscle qualities have been documented in literature. Jumping and sprinting are commonly used to investigate whether the ability to generate high forces could be the limiting factors to CODA. Dynamic strength, specifically relative back squat strength (back squat/BW), also has been reported as a crucial factor to sprint and COD performance. However, the paucity of research could not fully explain the underlying mechanisms between lower body strength qualities and COD performance. This study potentially connects the specific COD test that the movement pattern is similar to real soccer match. Consequently, straight-line sprinting and different lower body strength and power characteristics from loaded and unloaded vertical jumps and IMTP were examined to investigate the relationships with soccer specific COD. The findings from this study would be helpful to provide scientific evidence to coaches and strength and conditioning coaches when designing their programs. Ultimately, the results from this study would be beneficial for future research as well.

CHAPTER 3

STUDY I

Title: Effects of strength and power on change of direction and straight-line sprint performance in Division I soccer players: An exploratory study

Authors: Chieh-Ying. Chiang, Christopher A. Bailey, Kimitake Sato, Michael W. Ramsey, G. Gregory Haff, Michael H. Stone

Prepared for submission to *International Journal of Sport Physiology and Performance*

Abstract

Purpose: The aim of this investigation was to evaluate the relationships between lower body strength and power characteristics, change of direction (COD) and straight-line sprint performance in collegiate level soccer athletes. **Participants:** Twenty-four NCAA Division I soccer players participated in this study ($n = 12$ female and 12 male; age = 21 ± 1.4 y; body mass = 74.4 ± 10.3 kg). **Methods:** All subjects performed countermovement jumps (CMJs) and static jumps (SJ) with two loading conditions (0kg and 20kg). Jump height (JH) and Peak Power (PP) were calculated to examine lower body power characters. Isometric peak force (IPF), isometric forces (IF) at 50, 90 and 250 ms were also analyzed from Isometric mid-thigh pull (IMTP). Allometrically scaled variables (absolute force and power \cdot body mass^{-0.67}) were used for statistical analysis. A modified 5-5 COD and 10m-sprint tests were also measured to represent athletes' COD and sprinting performance.

Results: COD and 10m-sprint performance were statistically significantly related ($r = 0.54$ to 0.64 , $p < 0.05$). Moderate to strongly negative correlations were revealed between IMTP, COD and 10m-sprint ($r = -0.28$ to -0.65 , $p < 0.05$). Furthermore, JH was statistically associated with COD and 10m sprint times ($r = -0.41$ to -0.81 , $p < 0.05$). In addition, static jump height (SJH) could be used to predict COD total time (TT) ($R^2 = 0.64$). Stronger athletes also showed superior COD performance (ES= 0.32 to 1.50). **Conclusions:** Maximal strength appears to be closely related to soccer specific movements (COD & sprinting). Coaches and strength and conditioning coaches should aim to develop soccer athletes' maximal strength.

Key words: soccer, agility, vertical jump, maximal strength, athletic performance

INTRODUCTION

Soccer has become one of the most popular sports in the world, and is played by both sexes and different ages across all levels. The physical components in soccer, such as muscular strength, power, sprint speed and agility, have recently been given more attention by sport science and strength and conditioning fields (Chaouachi et al., 2012; Little & Williams, 2005). Although the importance of physical capacities in soccer players, such as lower body strength and power, have been reported by previous studies (Castillo-Rodríguez et al., 2012; Chamari et al., 2008; Vescovi & McGuigan, 2008), the interactions between strength, power characteristics and other physical demands, for instance, agility and sprinting, remains unclear.

Agility is one of the important physical contributions associated with soccer performance (Reilly, Williams, et al., 2000). Agility has been proposed as the ability to rapidly sprint and change of direction (COD) while also responding to outside stimuli (Sheppard & Young, 2006). Agility movements typically involve accelerating (short distance <10m), decelerating according to a stimulus (balls, opponents' defense, executing tactical strategies) and then changing to a new direction (Spiteri et al., 2013). Furthermore, COD speed and perceptual, decision-making have been suggested as key limiting factors underpinning athletes' agility performance (Sheppard & Young, 2006). Recently, the research objectives of agility studies have shifted to a topic that deals with the association of athletes' decision-making processes to sport-specific stimuli (G. Henry, Dawson, Lay, & Young, 2011; Serpell et al., 2011). A relatively small number of studies have investigated leg strength qualities and COD performance, especially using soccer athletes (Chaouachi et al., 2012; Vescovi & McGuigan, 2008).

Sprinting happens during a soccer match approximately every 70 seconds, each sprint lasting about 2 to 4 seconds (Stølen et al., 2005). Although the total distance covered by sprinting is only 1% to 11% of the total distance covered compared with other activities, straight sprinting is the most frequent scoring situation in soccer matches (Faude et al., 2012). Players also performed about 1300 changes of movement patterns every 4 to 6 seconds under off-the-ball conditions (Stølen et al., 2005). Based on the previously discussed evidence, it appears that COD and sprinting are two significant movements featured in soccer games.

To our knowledge, only one study has investigated the associations of soccer athletes' lower body power, straight-line sprinting and COD performance at the NCAA Division I level (Vescovi & McGuigan, 2008). Therefore, the main purpose of this study was to evaluate the relationships between various leg strength and power characteristics with straight sprint and COD performance in NCAA Division I soccer players. Additionally, maximal strength was examined to determine its effects on COD performance between strong and weak groups.

METHODS

Participants

Subjects for this study included 24 collegiate soccer players ($n = 12$ female and 12 male; age = 21 ± 1.4 y; body mass = 74.4 ± 10.3 kg) who participated and competed at NCAA Division I level. Data collection was part of a long-term athletes monitoring program at East Tennessee State University (ETSU). All participants read and signed informed consent documents that were approved by the ETSU Institutional Review Board. Each soccer athlete had prior experience in vertical jumps and isometric mid-thigh pull (IMTP) testing procedures that were performed in the ETSU Sport Science laboratory.

Experimental design

Soccer athletes performed vertical jump and IMTP testing after a standardized warm-up. The warm-up protocol has been described in a previous study (Kraska et al., 2009). The COD tests were then performed. Ten-meter sprint tests were assessed on a soccer field at least 24 hours after vertical jumps, IMTP and COD tests.

Vertical jump tests

Countermovement jumps (CMJ) and static jumps (SJ) with loaded (20kg barbell) and unloaded (0kg PVC pipe) conditions were performed on a force plate (Rough Deck HP; Rice Lake, WI), while data were sampled at 1,000 Hz. Vertical jump tests started with the SJ. Athletes stood on a force plate and squatted down to a knee angle at 90° as measured by goniometer. Jumps commands were given after athletes stayed in this bottom position for three seconds. Two trials of each jump (SJ 0kg and SJ 20kg) were completed with 1 minute of rest between each trial. CMJs were tested approximately 3 min after the SJs to remove any potential neuromuscular fatigue. Athletes performed a CMJ after descending to a self-selected depth. Two trials of two loaded conditions (CMJ 0kg and CMJ 20kg) were also executed with one minute of rest between trials. The average of each trial (loaded and unloaded SJ and CMJ) was used for analysis. Eight jumps from SJs and CMJs were measured and variables analyzed from SJs and CMJs included: SJ jump height (SJH, 0kg and 20kg), CMJ jump height (CMJH, 0kg and 20kg), SJ allometric scaled peak power (SJ PPa, 0kg and 20kg) and CMJ allometric scaled peak power (CMJ PPa, 0kg and 20kg). Allometric scaled calculations were based on Kraska et al. (2009) and Jaric (2002) which were computed by $\text{absolute power} \cdot \text{body mass}^{-0.67}$). A customized Labview10.0 software program (National

Instruments Co., Austin, TX) was used to analyze all force-time data. A digital low pass Butterworth filter with a cutoff frequency of 10 Hz was used to remove electrical noise.

Isometric Mid-thigh Pull (IMTP)

Lower body maximal strength was measured by the IMTP test. The standard protocol was based on a previous study (Bailey et al., 2013). IMTP was tested on the dual force plate built into a customized rack (Figure 3.1). Athletes used the weightlifting straps and were taped to the bar to ensure the grips strength was not the limiting factor while performing a maximal effort. Bar height was adjusted to each individual's knee angle at $175^{\circ} \pm 5^{\circ}$ and $125^{\circ} \pm 5^{\circ}$ respectively. This position has been shown to produce the highest peak force (Beckham et al., 2013). Then athletes were performed two warm-up trials at approximately 50% and 75% of maximal effort. Two maximal pulls were executed. The duration for each trial was approximately 3 to 4 sec with 2 min rest between trials. Again, data from two trials on averaged prior to statistical analysis. Allometric scaled Isometric peak force (IPFa), and allometric scaled instantaneous force at 50, 90 and 250ms (F50a, F90a and F250a) were used in this study. A customized Labview10.0 software program (National Instruments Co., Austin, TX) was utilized to analyze force-time data. A digitized signal was filtered using a 4th order Butterworth low-pass filter at 100 Hz.

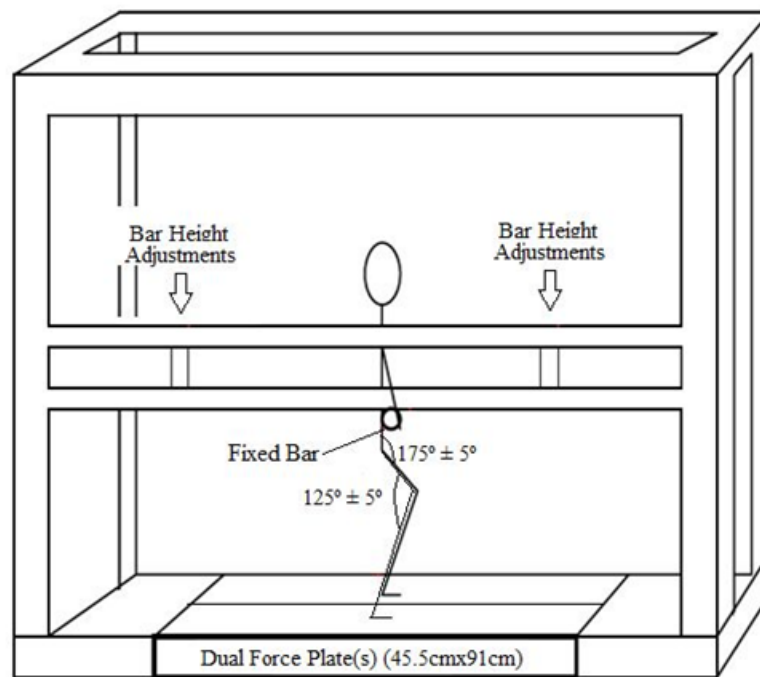


Figure 3.1. Schematic approach of IMTP test set up

Change of Direction (COD) test

A modified 505 COD test was used to evaluate athletes' COD performance (Figure 3.2). Athletes were required to sprint 5m, perform a 180° turn and sprint back to the starting line. Each athlete had two familiarization trials, performed at about 50% and 75% of perceived maximal effort, in order to minimize the perceptual and decision making component involved in the real trials. A total of 4 trials were recorded (two trials performed cutting with left leg, and two trials with right leg), with at least 1 min between each trial. Two sets of timing gates were used to assess athletes' 3m acceleration time (3mAcc), total time (TT) and partial time (PT). PT was calculated by subtracting athletes' 3mAcc by their TT. These three variables represent athletes' abilities to accelerate and re-accelerate during typical COD tasks (Spiteri et al., 2013).

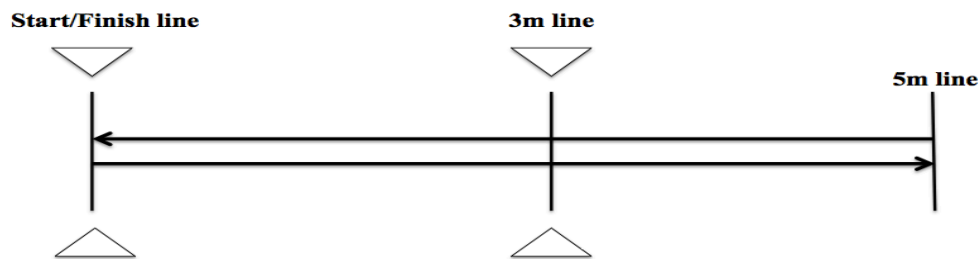


Figure 3.2. Schematic approach of COD test

Ten-meter sprint

The 10m-sprint test was measured to evaluate athletes' acceleration ability. About 10min of dynamic warm-up was implemented prior to the straight sprint test. The dynamic warm-up included light jogging (1min), 10 stationary body weight squats, 10m walking lunge, and dynamic stretches of hip, thigh and calf muscles. Two submaximal 10m sprints at 50% and 75% maximal effort were employed as last part of warm-up session. After 3min rest, each player performed two trials of 10m straight-line sprints. Sprints were interspersed with approximately 2min rest between each trial. The test began using a staggered stance with the

front foot was placed 0.5m behind the starting line. Three sets of timing gates were set up 5m apart to measure athletes' acceleration time. Acceleration time from 5m (Acc5), 10m (Acc10) and 5-10m (Acc5-10) were recorded.

Statistical analysis

The test-retest reliability of all tests in this study was calculated using intraclass correlation coefficient (ICC) with 95% confidence intervals (CI) and coefficient of variations (CV). The relationships of COD, 10m-sprint, IMTP and vertical jumps were assessed using Pearson's zero order product-moment correlations. Prediction of TT was performed via stepwise multiple regression analysis. In addition, independent samples *t*-tests were used to compare IPFa and COD variables between the strong and the weak groups. A Holm-Bonferroni sequential adjustment was used to avoid type I error (initial *p* value set up at 0.05). The strong group was identified as athletes who performed at the top 25% of the IPFa from IMTP test (*n* = 6, 3 male and 3 female). The weak group was defined as the bottom 25% of IPFa of all participants (*n* = 6, 3 male and 3 female). The strength of relationship was based on Hopkins (2002), in which *r* ≤ 0.30 is moderate; *r* ≤ 0.50 is strong; *r* ≤ 0.70 is very strong; *r* ≤ 0.90 is nearly perfect; *r* ≤ 1.00 is perfect. Cohen's effect sizes (*d*) were also calculated. Effect sizes are described by Cohen (1988) as small (*d* ≤ 0 to 0.19), moderate (*d* = 0.2 to 0.8), and large (*d* ≥ 0.8). Statistical significance was set at an alpha level of *P* ≤ 0.05. SPSS software 21.0 version was used to analyze all statistical calculation (IBM Co., NY, USA).

RESULTS

The test-retest reliability for COD and 10m-sprint variables are displayed in Table 3.1, ICC are between 0.72 to 0.96, and CV are between 4.6 % to 8.0 %. Further, the reliability for all IMTP and vertical jumps variables are ICCs > 0.96, and CVs are < 3%. Table 3.2 shows the correlation results between COD and 10m-sprint tests. 3mA was statistically correlated with TT ($r=0.71, p < 0.001$), TT and PT were also strongly and significantly correlated with each other ($r = 0.90, p < 0.001$). Acc5 was strongly correlated to Acc10, as well as the relationship between Acc5-10 and Acc10 ($r = 0.80$ to $0.85, p < 0.001$). Furthermore, TT and PT were strongly related to Acc5-10 and Acc10 ($r = 0.54$ to 0.64). The relationships between IMTP, COD and 10m-sprint tests are displayed in Table 3.3. Strong and statistically significant negative relationships were found between IPFa, 3mA, TT and PT ($r = -0.53$ to -0.65). All 10m-sprint variables demonstrated small to moderate correlations with IPFa ($r = -0.28$ to -0.40). Additionally, F250a and TT, F250a and Acc10 were significantly and moderately correlated ($r = -0.41, p = 0.05$).

Statistically significant moderate to very strong negatively correlations were revealed between COD and vertical jump variables ($r = -0.41$ to $-0.81, p < 0.05$)(Table 3.4). Although not reaching statistical significance, small to moderate correlations were found such as CMJ PPa 0kg and 3mA ($r = -0.36$), CMJ PPa 20kg and 3mA ($r = -0.33$), SJ PPa 0kg and 3mA($r = -0.37$) and CMJH 20kg and Acc5 ($r = -0.37$). In addition, IPFa and eight vertical jumps were significantly strong to very strong correlated ($r = 0.55$ to $0.75, p < 0.05$). Stepwise multiple regression analysis shows SJH 0kg accounted for 64% (adjusted $R^2 = 0.64, p < 0.001$) of the variance in COD TT.

Additional comparisons between the strong and the weak group on IPFa and COD performance were displayed in Table 3.5. A statistically significant difference was found in IPFa between the two groups ($p < 0.05, ES = 1.50$). There was no statistical significance

found for COD variables between the strong and the weak group. However, moderate to large effect sizes ($ES = 0.32$ to 1.25) were discovered which suggest practical significance.

Table 3.1. Test-retest reliability base on ICC and CV for COD and 10m-sprint variables

	ICC (95% CI)	CV (%)
3mA	0.89 (0.82-0.94)	8.06
TT	0.96 (0.92-0.97)	5.32
PT	0.87 (0.79-0.93)	5.75
Acc5	0.72 (0.70-0.84)	5.10
Acc5-10	0.88 (0.74-0.93)	4.63
Acc10	0.82 (0.77-0.90)	6.40

ICC = intraclass correlation coefficient, CV = coefficient of variation, COD = change of direction, IMTP = Isometric mid-thigh pull, CI = confidence interval, 3mA = 3 meter approach time, TT = total test time, PT = partial time, Acc5 = 5m acceleration time, Acc5-10 = 5m to 10m acceleration time, Acc10 = 10m acceleration time.

Table 3.2. Relationships between COD and 10m-sprint performance

	3mA (s)	TT (s)	PT (s)	Acc5 (s)	Acc5-10 (s)	Acc10 (s)
3mA (s)	1					
TT (s)	0.71***	1				
PT (s)	0.32	0.90***	1			
Acc5 (s)	0.29	0.34	0.27	1		
Acc5-10 (s)	0.32	0.63***	0.64***	0.34	1	
Acc10 (s)	0.37	0.58**	0.54**	0.85***	0.80***	1

COD = change of direction, 3mA = 3 meter approach time, TT = total test time, PT = partial time, Acc5 = 5m acceleration time, Acc5-10 = 5m to 10m acceleration time, Acc10 = 10m acceleration time, ** = $p < 0.01$, *** = $p < 0.001$

Table 3.3. Relationships between IMTP, COD, and 10m-sprint performance.

	3mA (s)	TT (s)	PT (s)	Acc5 (s)	Acc5-10 (s)	Acc10 (s)
IPF _a (N·kg ^{-0.67})	-0.55 ^{**}	-0.65 ^{**}	-0.53 ^{**}	-0.28	-0.39	-0.40
F50 _a (N·kg ^{-0.67})	-0.35	-0.34	-0.23	-0.29	-0.19	-0.30
F90 _a (N·kg ^{-0.67})	-0.34	-0.35	-0.25	-0.27	-0.26	-0.32
F250 _a (N·kg ^{-0.67})	-0.34	-0.41 [*]	-0.34	-0.30	-0.38	-0.41 [*]

IMTP = Isometric mid-thigh pull, COD = change of direction IPF_a = allometrically scaled isometric peak force, F50_a = allometrically scaled instant force at 50ms, F90_a = allometrically scaled instant force at 50ms, F250_a = allometrically scaled instant force at 250ms, 3mA = 3 meter approach time, TT = total test time, PT = partial time, Acc5 = 5m acceleration time, Acc5-10 = 5m to 10m acceleration time, Acc10 = 10m acceleration time, ^{*} = $p < 0.05$, ^{**} = $p < 0.01$

Table 3.4. Relationship between vertical jump variables, COD, and 10m-sprint performance.

	3mA (s)	TT (s)	PT (s)	Acc5 (s)	Acc5-10 (s)	Acc10 (s)
CMJH 0kg (cm)	-0.43 [*]	-0.71 ^{***}	-0.68 ^{***}	-0.40	-0.71 ^{***}	-0.67 ^{***}
CMJH 20kg (cm)	-0.43 [*]	-0.71 ^{***}	-0.69 ^{***}	-0.37	-0.64 ^{***}	-0.61 ^{**}
CMJ PP _a 0kg (W·kg ^{-0.67})	-0.36	-0.62 ^{**}	-0.60 ^{**}	-0.43 [*]	-0.56 ^{**}	-0.60 ^{**}
CMJ PP _a 20kg (W·kg ^{-0.67})	-0.33	-0.61 ^{**}	-0.61 ^{**}	-0.43 [*]	-0.52 ^{**}	-0.57 ^{**}
SJH 0kg (cm)	-0.46 [*]	-0.81 ^{***}	-0.79 ^{***}	-0.44 [*]	-0.77 ^{***}	-0.72 ^{***}
SJH 20kg (cm)	-0.41 [*]	-0.71 ^{***}	-0.70 ^{***}	-0.41 [*]	-0.65 ^{***}	-0.64 ^{***}
SJ PP _a 0kg (W·kg ^{-0.67})	-0.37	-0.68 ^{***}	-0.68 ^{***}	-0.47 [*]	-0.57 ^{**}	-0.63 ^{**}
SJ PP _a 20kg (W·kg ^{-0.67})	-0.24	-0.54 ^{**}	-0.57 [*]	-0.50 [*]	-0.49 [*]	-0.60 ^{**}

COD = change of direction, 3mA = 3 meter approach time, TT = total test time, PT = partial time, Acc5 = 5m acceleration time, Acc5-10 = 5m to 10m acceleration time, Acc10 = 10m acceleration time, CMJH = countermovement jump high, CMJ PP_a = allometrically scaled peak power of countermovement jump, SJH = static jump high, SJ PP_a = allometrically scaled peak power of static jump, ^{*} = $p < 0.05$, ^{**} = $p < 0.01$, ^{***} = $p < 0.001$

Table 3.5. Comparison of IPF_a and COD performance between the strong and weaker groups (mean \pm SD).

	Strong group (n= 6)	Weak group (n= 6)	<i>p</i>	ES
IPF _a (N·kg ^{-0.67})	247.65 \pm 53.51*	179.54 \pm 34.95*	0.02	1.50
3mA (s)	0.84 \pm 0.09	0.93 \pm 0.03	0.07	1.25
TT (s)	2.78 \pm 0.13	2.90 \pm 0.13	0.14	0.91
PT (s)	1.94 \pm 0.06	1.97 \pm 0.12	0.58	0.32

IPF_a = allometrically scaled isometric peak force, COD = change of direction, 3mA = 3 meter approach time, TT = total test time, PT = partial time, * = $p < 0.05$

DISCUSSION

The primary findings from this study were a) COD and 10m-sprint performance were closely associated. Subjects were more likely to finish both tests faster if they accelerated quicker for the first few meters. b) Maximal strength was relevant to COD and 10m-sprint abilities and IPF_a and F250a displayed similar relationships with both tests. c) Vertical jumps are highly correlated to COD and 10m-sprint performance. d) Stronger athletes showed superior COD ability.

Correlation between COD test and 10m-sprint performance

The relationships between 3mA, PT, and TT during COD test were very strong ($r = 0.71$ to 0.90 , $p < 0.001$). These results suggest that those who accelerate faster during the first 3m, and re-accelerate after turning to a new direction were more likely to finish the COD test in a shorter time. Furthermore, athletes who could sprint faster for the first 5m (Acc5) and from 5m to 10m (Acc5-10) during the 10m-sprint test, performed superiorly in the overall 10m-sprint test ($r = 0.80$ to 0.85 , $p < 0.001$). This finding is in accordance with other studies (Chaouachi et al., 2012; Jones et al., 2009). In addition, strong relationships were revealed between COD (TT and PT) and 10m sprint (Acc5-10 and Acc10) variables ($r = 0.54$ to 0.64 , $p < 0.05$). This may indicate some transfer effects from COD to 10m sprint, or vice versa. However, different results were reported by Little and Williams (2005) who found only a small shared variance ($r^2 = 0.11$) between 10m sprint test and Zigzag COD tests in professional soccer athletes. The inconsistent findings may be due to the different COD

assessment methods and skill level (Brughelli et al., 2008). In our study, athletes only completed one COD movement during the task; the Zigzag test requires athletes to perform a total of 3 COD movements to complete the task. In order to examine the interactions between these two important physical capacities in soccer populations, designing the COD tests that are more specific to soccer match demands, such as work to rest ratio and numbers of COD are needed.

Correlation between IMTP, COD, 10m sprint and performance

Statistically significant relationships were discovered between IPFa and COD variables ($r = -0.53$ to -0.65 , $p \leq 0.05$), suggesting maximal strength was critical while performing the COD test. This is in complete agreement with Wisløff et al. (2004). They found a strong correlation between elite soccer players' 1RM half squat and 10m COD shuttle run ($r = -0.64$). Previous studies have shown the relations between athletic movements (striking, sprinting and jumping) and force production at different critical periods (50, 90 and 250ms) (Kraska et al., 2009; Schmidtbleicher, 1992). To our knowledge, this is the first study to report the statistically significant relationships between F250a and TT ($r = -0.41$, $p = 0.01$). The exact underlying mechanisms are still unknown, as a result, future research is needed. On the other hand, F250a also showed a statistically significant and moderate correlation with Acc10m ($r = -0.41$, $p = 0.04$), similar to previous reports, showing maximal strength has contributed to athletes' sprint ability (Chaouachi et al., 2009; Cunningham et al., 2013; Nimphius et al., 2010; Wisløff et al., 2004). Both COD and 10m sprint tests in this study required athletes to start the movements from a static position, and maximal strength might play a role to overcome the inertia. Based on Newton's second law: $F = ma$, the ability to accelerate (a) a mass (m), such as body mass or external object, depends on the ability of the musculature to generate force (F) (Stone et al., 2006). Therefore, the ability to generate

maximal force and force at different time frames, such as 250ms, appears to be critical for the COD and 10m-sprint performance in collegiate soccer athletes.

Correlation between vertical jumps power, COD and 10m-sprint performance.

Vertical jump variables, which were used to represent soccer players' lower body power, were highly negatively correlated to COD and 10m-sprint performance. Particularly in the COD test, TT ($r = -0.54$ to -0.81 , $p < 0.05$) and PT ($r = -0.57$ to -0.79 , $p < 0.05$) showed the highest correlations with vertical jump variables. Similar results have also been reported in a previous study (Castillo-Rodríguez et al., 2012). In vertical jumps, especially static jumps, athletes start their explosive movements from a squatting position, which may be similar to the transition phase from a deceleration to a re-acceleration movement. Additionally, the strong to very strong relationships were found between CMJs and COD performance ($r = -0.60$ to -0.71 , $p < 0.05$). These results appear to be consistent with those reported by Chaouachi et al. (2012). It should be noted that CMJs and SJs likely represent somewhat different mechanisms for power generation in musculature systems (Stone et al., 2007), and future investigations needed to clarify the different underlying mechanisms between COD tasks and vertical jumps.

In this study, moderate to very strong relationships were revealed ($r = -0.37$ to -0.77 , $p < 0.05$) between the 10m sprint and vertical jumps variables. These results are fairly consistent with previous studies (Cronin & Hansen, 2005; Sleivert & Taingahue, 2004; Vescovi & McGuigan, 2008). Interestingly, SJH 0kg showed the highest negative correlation with Acc5-10 ($r = -0.77$, $p < 0.001$) and Acc10 (-0.72 , $p < 0.001$). Due to the nature of a rapid stretch shortening in sprinting, studies have often used CMJs because of the muscle contact pattern similarities. Supporting explanations underlying the strong relationship for the SJ remains unknown and future research is needed.

In the present study multiple regression analysis to predict COD TT, similar to Barnes et al. (2007). Variables chosen were those displayed highest correlations ranging from -0.71 to -0.81 and the SJH 0kg was the best fitting predictor for COD TT, which explained 64% of variance. Our data are in contrast to those of Barnes et al. (2007) who found the CMJH is the best predictor of COD test. However, it should be noted, the subjects from their study were females volleyball players, ranging from NCAA Division I to Division III levels. Moreover, CMJs have been shown to be the most commonly used jumping movement in volleyball matches (Ziv & Lidor, 2010). This movement specificity might explain the difference in predictability for COD performance among different sports, and may also indicate that relationships between dynamic strength and COD performance are associated with sport/population tested.

Correlation between IMTP and vertical Jumps

It is worth noting that the associations found between all vertical jumps variables and IPFa ($r = 0.54$ to 0.75 , $p < 0.05$) were in line with previous reported research (Kraska et al., 2009; Nuzzo, McBride, Cormie, & McCaulley, 2008; Stone et al., 2003). In order to achieve maximal acceleration during jump, athletes were needed to push against ground and generate forces in a maximal effort. Thus, vertical jump height and other performance variables depend on athletes' ability to produce high forces during a very short amount of time (Kraska et al., 2009; Stone et al., 2007). Typically, greater strength levels are associated with higher rates of force development (RFD) (Schmidtbleicher, 1992; Stone et al., 2007). This phenomenon could also explain the similar finding in this study, where IPFa was vital to performing in the vertical jumps.

Comparison

To our knowledge, this study is the first investigation to demonstrate the importance of soccer athletes' maximal strength and 3mA, which represented as athletes' initial acceleration ability at NCAA Division 1 level. Previous investigations demonstrate that stronger athletes could sprint faster (McBride et al., 2009), jump higher (Kraska et al., 2009), and have faster post-COD strides (the ability to re-accelerate)(Spiteri et al., 2013). In our study, the strong group demonstrated significantly higher IPFa when compared to the weak group ($p = 0.02$, $ES = 1.5$). The strong group also showed the tendency performed superiorly during 3mA ($ES = 1.25$), TT ($ES = 1.25$), and PT ($ES = 0.32$). In sports settings, this initial acceleration ability often referred to as “quick feet” or “a quick first step”. However, there are only a few studies that have examined the relationships between athletes' strength qualities and initial acceleration performance ($< 5m$) (Jones et al., 2009; Sleivert & Taingahue, 2004). According to our results, soccer coaches and strength and conditioning coaches who desire their athletes to perform better regarding initial acceleration, should consider developing their players' maximal strength.

PRACTICAL APPLICATIONS

Strength and power characteristics are vital for collegiate soccer players' as there is a direct relationship between these attributes and straight-line sprinting and COD performance. According to previous literature, maximal strength plays a role as the fundamental base of power production (Cormie, McGuigan, & Newton, 2011; Stone et al., 2007). Based upon this data and the findings of present study that stronger athletes are more powerful than their weaker counterpart during COD tasks. Furthermore, the results of this study confirmed the idea that stronger athletes not only jump higher (Kraska et al., 2009), sprint faster (McBride et al., 2009), but also perform better during COD tests (Keiner, Sander, Wirth, & Schmidtbleicher, 2014; Spiteri et al., 2013). Therefore, athletes who need to execute

explosive movements should incorporate training for maximal strength into their strength and physical preparation program.

Most studies have used 1 RM squat to represent athletes' maximal leg strength (Chaouachi et al., 2009; Hori et al., 2008; Keiner et al., 2014; McBride et al., 2009; Nimphius et al., 2010; Wisløff et al., 2004). Notice that data from our study found COD and straight sprint performance was relevant to force production at 250ms. Future study may consider using IMTP to examine the relationships between different leg strength qualities and specific athletic movements (Stone et al., 2007). The data also revealed that vertical jumps (SJs and CMJs) are closely related to soccer athletes' COD and 10m-sprint performance. Thus, sport scientists and strength and conditioning coaches should consider including IMTP and vertical jumps into their total athletes monitoring programs.

CONCLUSION

Despite encouraging results of this study, questions remain unsolved. The exact interactions regarding the complex strength qualities displayed during COD tasks, such as different movement phases (acceleration, braking, cutting and re-acceleration) and force production asymmetry (left vs right; dominant vs no-dominant). Future investigations are needed. Results from this study revealed that vertical jumps (with two loading conditions) and maximal strength are closely related to NCAA Division I collegiate soccer players' COD test and 10m straight sprint. Additionally, COD performance can be predicted by SJH during the 0kg condition. Moreover, stronger soccer players not only displayed higher maximal strength through IMTP, but also performed superiorly in 3mA and TT during COD test.

REFERENCES

- Bailey, C., Sato, K., Alexander, R., Chiang, C. Y., & Stone, M. H. (2013). Isometric force production symmetry and jumping performance in collegiate athletes. *Journal of Trainology*, 2, 1-5.
- Barnes, J. L., Schilling, B. K., Falvo, M. J., Weiss, L. W., Creasy, A. K., & Fry, A. C. (2007). Relationship of jumping and agility performance in female volleyball athletes. *Journal of Strength and Conditioning Research*, 21(4), 1192-1196. doi: 10.1519/R-22416.1
- Brughelli, M., Cronin, J., Levin, G., & Chaouachi, A. (2008). Understanding change of direction ability in sport: a review of resistance training studies. *Sports Medicine*, 38(12), 1045-1063. doi: 10.2165/00007256-200838120-00007
- Castillo-Rodríguez, A., Fernández-García, J., Chinchilla-Minguet, J., & Carnero, E. Á. (2012). Relationship between muscular strength and sprints with changes of direction. *The Journal of Strength & Conditioning Research*, 26(3), 725-732.
- Chamari, K., Chaouachi, A., Hambli, M., Kaouech, F., Wisloff, U., & Castagna, C. (2008). The five-jump test for distance as a field test to assess lower limb explosive power in soccer players. *Journal of Strength and Conditioning Research*, 22(3), 944-950. doi: Doi 10.1519/Jsc.0b013e31816a57c6
- Chaouachi, A., Brughelli, M., Chamari, K., Levin, G. T., Ben Abdelkrim, N., Laurencelle, L., & Castagna, C. (2009). Lower limb maximal dynamic strength and agility determinants in elite basketball players. *Journal of Strength and Conditioning Research*, 23(5), 1570-1577. doi: 10.1519/JSC.0b013e3181a4e7f0
- Chaouachi, A., Manzi, V., Chaalali, A., Wong del, P., Chamari, K., & Castagna, C. (2012). Determinants analysis of change-of-direction ability in elite soccer players. *Journal of*

- Strength and Conditioning Research*, 26(10), 2667-2676. doi: 10.1519/JSC.0b013e318242f97a
- Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2 ed ed.). Hillsdale: Lawrence Erlbaum Associates.
- Cormie, P., McGuigan, M. R., & Newton, R. U. (2011). Developing maximal neuromuscular power Part 1-biological basis of maximal power production. *Sports Medicine*, 41(1), 17-38. doi: Doi 10.2165/11537690-000000000-00000
- Cronin, J. B., & Hansen, K. T. (2005). Strength and power predictors of sports speed. *Journal of Strength and Conditioning Research*, 19(2), 349-357. doi: 10.1519/14323.1
- Cunningham, D. J., West, D. J., Owen, N. J., Shearer, D. A., Finn, C. V., Bracken, R. M., . . . Kilduff, L. P. (2013). Strength and power predictors of sprinting performance in professional rugby players. *Journal of Sports Medicine and Physical Fitness*, 53(2), 105-111.
- Faude, O., Koch, T., & Meyer, T. (2012). Straight sprinting is the most frequent action in goal situations in professional football. *Journal of Sports Sciences*, 30(7), 625-631. doi: Doi 10.1080/02640414.2012.665940
- Henry, G., Dawson, B., Lay, B., & Young, W. (2011). Validity of a reactive agility test for Australian football. *International Journal of Sports Physiology and Performance*, 6(4), 534-545.
- Hopkins, W. (2002). A scale of magnitudes for effect statistics. Available from URL: www.sportsci.org/resource/stats/effectmag.html
- Hori, N., Newton, R. U., Andrews, W. A., Kawamori, N., McGuigan, M. R., & Nosaka, K. (2008). Does performance of hang power clean differentiate performance of jumping, sprinting, and changing of direction? . *Journal of Strength and Conditioning Research*, 22(2), 412-418.

- Jones, P., Bampouras, T. M., & Marrin, K. (2009). An investigation into the physical determinants of change of direction speed. *Journal of Sports Medicine and Physical Fitness*, 49(1), 97-104.
- Keiner, M., Sander, A., Wirth, K., & Schmidtbleicher, D. (2014). Long-term strength training effects on change-of-direction sprint performance. *Journal of Strength and Conditioning Research*, 28(1), 223-231. doi: 10.1519/JSC.0b013e318295644b
- Kraska, J. M., Ramsey, M. W., Haff, G. G., Fethke, N., Sands, W. A., Stone, M. E., & Stone, M. H. (2009). Relationship between strength characteristics and unweighted and weighted vertical jump height. *International Journal of Sports Physiology and Performance*, 4(4), 461-473.
- Kunz, M. (2007). Big count: 265 million playing football. *Fifa Magazine*, 10-15.
- Little, T., & Williams, A. G. (2005). Specificity of acceleration, maximum speed, and agility in professional soccer players. *Journal of Strength and Conditioning Research*, 19(1), 76-78. doi: 10.1519/14253.1
- McBride, J. M., Blow, D., Kirby, T. J., Haines, T. L., Dayne, A. M., & Triplett, N. T. (2009). Relationship between maximal squat strength and five, ten, and forty yard sprint times. *Journal of Strength and Conditioning Research*, 23(6), 1633-1636. doi: Doi 10.1519/Jsc.0b013e3181b2b8aa
- Nimphius, S., McGuigan, M. R., & Newton, R. U. (2010). Relationship between strength, power, speed, and change of direction performance of female softball players. *Journal of Strength and Conditioning Research*, 24(4), 885-895. doi: Doi 10.1519/Jsc.0b013e3181d4d41d
- Reilly, T., Williams, A. M., Nevill, A., & Franks, A. (2000). A multidisciplinary approach to talent identification in soccer. *Journal of Sports Sciences*, 18(9), 695-702. doi: 10.1080/02640410050120078

- Schmidtbleicher, D. (1992). Training for power events. . In P. V. Komi (Ed.), *Strength and power in sport* (pp. 381-395). London: Blackwell Scientific Publication.
- Serpell, B. G., Young, W. B., & Ford, M. (2011). Are the perceptual and decision-making components of agility trainable? A preliminary investigation. *Journal of Strength and Conditioning Research*, 25(5), 1240-1248.
- Sheppard, J. M., & Young, W. B. (2006). Agility literature review: classifications, training and testing. *Journal of Sports Sciences*, 24(9), 919-932. doi: 10.1080/02640410500457109
- Sleivert, G., & Taingahue, M. (2004). The relationship between maximal jump-squat power and sprint acceleration in athletes. *European Journal of Applied Physiology*, 91(1), 46-52. doi: Doi 10.1007/S00421-003-0941-0
- Spiteri, T., Cochrane, J. L., Hart, N. H., Haff, G. G., & Nimphius, S. (2013). Effect of strength on plant foot kinetics and kinematics during a change of direction task. *European Journal of Sport Science*, 13(6), 646-652.
- Stolen, T., Chamari, K., Castagna, C., & Wisloff, U. (2005). Physiology of soccer: an update. *Sports Medicine*, 35(6), 501-536.
- Stone, M. H., O'Bryant, H. S., McCoy, L., Coglianese, R., Lehmkuhl, M., & Schilling, B. (2003). Power and maximum strength relationships during performance of dynamic and static weighted jumps. *Journal of Strength and Conditioning Research*, 17(1), 140-147.
- Stone, M. H., Stone, M., & Sands, W. A. (2007). *Principles and practice of resistance training*. Champaign, IL: Human Kinetics
- Stone, M. H., Stone, M. E., Sands, W. A., Pierce, K. C., Newton, R. U., Haff, G. G., & Carlock, J. (2006). Maximum strength and strength training---a relationship to endurance? *Strength & Conditioning Journal*, 28(3), 44-53.

- Vescovi, J. D., & McGuigan, M. R. (2008). Relationships between sprinting, agility, and jump ability in female athletes. *Journal of Sports Sciences*, 26(1), 97-107. doi: 10.1080/02640410701348644
- Wisloff, U., Castagna, C., Helgerud, J., Jones, R., & Hoff, J. (2004). Strong correlation of maximal squat strength with sprint performance and vertical jump height in elite soccer players. *British Journal of Sports Medicine*, 38(3), 285-288.
- Young, W. B., McDowell, M. H., & Scarlett, B. J. (2001). Specificity of sprint and agility training methods. *Journal of Strength and Conditioning Research*, 15(3), 315-319.
- Ziv, G., & Lidor, R. (2010). Vertical jump in female and male volleyball players: a review of observational and experimental studies. *Scandinavian Journal of Medicine and Science in Sports*, 20(4), 556-567. doi: 10.1111/j.1600-0838.2009.01083.

CHAPTER 4

STUDY II

Title: Bilateral strength asymmetry does not effect change of direction performance in college soccer athletes: An exploratory study

Authors: Chieh-Ying. Chiang, Christopher A. Bailey, Kimitake Sato, Michael W. Ramsey, G. Gregory Haff, Michael H. Stone

Paper prepared for submission to *European Journal of Applied Physiology*

Abstract

Purpose: Asymmetry in sports has been discussed; however, there is limited literature examining the relationships between asymmetry and change of direction (COD) performance. The aim of this study was to evaluate the interrelations between leg strength asymmetry and COD performance among college soccer athletes. **Methods:** Twenty- seven NCAA Division I soccer athletes participated in this study (n =15 female and 12 male; age = 21 ± 1.3 y; body mass = 73.5 ± 0.4 kg). A modified 505 COD test was used to assess athletes' COD performance. Isometric mid-thigh pull (IMTP) testing on force plates was also utilized to measure bilateral strength asymmetry. Isometric peak force (IPF) and forces at 50 (F50), 90(F90) and 250(F250) ms were recorded for statistical analyses. Symmetry index (SI) scores were calculated for both COD and IMTP tests. **Results:** Significant relationships were discovered between F50, F90 and partial time (PT) in the COD test ($r = 0.42$ and 0.60 , $p < 0.05$). No statistical differences were found between strength dominant (SD) and non-strength dominant (NSD) legs on COD performance ($p > 0.05$). Additional analyses also revealed no performance differences in COD test variables between the less asymmetric group (IPF SI $< 4\%$) and more asymmetric group (IPF SI $> 4\%$). **Conclusion:** Athletes who had more force production asymmetry during IMTP at 50ms and 90ms between legs, were more likely to perform asymmetrically during COD test. However, SD and the magnitude of asymmetry during the IMTP do not seem not to be factors that affect subjects' COD performance.

Key Words: bilateral strength asymmetry, agility, soccer, athletes' performance

Introduction

Asymmetry in sports, such as range of motion, flexibility, limb mass, weight distribution (WtD) and force production, has been gaining interest in sport science related investigations. The relationships between asymmetry and performance outcomes have been discussed in scientific literature (Bailey et al., 2013; Bazyler, Bailey, Chiang, Sato, & Stone, 2014; Hart, Nimphius, Spiteri, & Newton, 2014; Hewit et al., 2012a; Hoffman et al., 2007; Meylan et al., 2009; Sato & Heise, 2012).

Sato and Heise (2012) reported that WtD asymmetry over six percent during the squat exercise possibly increased the risk of barbell tilt and rotation. Bailey et al. (2013) found force production asymmetry during an isometric mid-thigh pull (IMTP) was likely to influence vertical jump performance in collegiate athletes. In this particular study, moderate to strong negative correlations were reported between IMTP peak force (PF) asymmetry, jump height (JH) and peak power (PP). Thus, more asymmetry occurring during IMTP might decrease athletes' jumping ability. Similar results were also found between force and power production asymmetry and vertical JH (Bell, Sanfilippo, Binkley, & Heiderscheit, 2014).

Athletes participating in team sports are often required to perform sudden acceleration, deceleration and change of direction (COD). After decelerating, athletes need to overcome their own body weight and momentum, in order to push off and turn in a new direction. This kind of movement is commonly completed unilaterally. Recently, the topic of the unilateral strength, power and COD performance in team sport athletes has drawn investigators' attention (Chaouachi et al., 2012; G. J. Henry et al., 2013; Hoffman et al., 2007; Meylan et al., 2009; Spiteri et al., 2013; Young et al., 2002). Young et al. (2002) examined the relationships between unilateral leg concentric power, reactive strength and COD performance in club level male athletes who participated in basketball, tennis and Australian football. No statistically significant correlations were found between unilateral power outputs

and COD tests; however, some moderate and statistically significant coefficients were found between the right side reactive strength score and COD tests. It was concluded that the participants who turned faster on one side tended to have a higher reactive strength performance.

The other study by Hoffman et al. (2007) found a statistically significant difference of unilateral jump power outputs between dominant (D) and non-dominant (ND) sides. However, the power deficit between D and ND ($9.7 \pm 6.9\%$) did not relate to COD performance. Meylan et al. (2009) reported that horizontal unilateral jumps on both D and ND sides had negative correlations with COD performance in men and female recreational athletes ($r = -0.47$ to -0.59). Furthermore, a study by Spiteri et al. (2013) also found that stronger athletes have demonstrated higher forces and impulse from the D side during a COD task compared to their weaker counterparts (Spiteri et al., 2013). While bilateral strength asymmetry is becoming more prevalent, no study has examined the effects of bilateral strength asymmetry on COD performance.

Therefore, the primary purpose of this investigation was to determine if the asymmetry in a COD task is related to force production asymmetry during an IMTP test. The secondary purpose of this investigation was to examine whether the strength dominant (SD) side during IMTP test showed a superior COD performance than non-strength dominant side. Furthermore, the magnitude of bilateral strength asymmetry was also calculated to assess if the higher strength asymmetry affected the performance differences on COD performance.

Methods

Athletes

This study included 27 collegiate soccer players ($n=15$ female and 12 male; age = 21 ± 1.3 y; body mass = 73.5 ± 0.4 kg) who participated and competed at NCAA Division I level. Data collection was part of a long-term athletes monitoring program at East Tennessee State University (ETSU). All participants read and signed informed consent documents that were approved by the university's Institutional Review Board. Each soccer athlete had prior experience in IMTP testing procedures that were performed in the ETSU Sport Science Laboratory.

Experimental design

The COD and IMTP tests were conducted on the same testing day. Prior to COD test, athletes went through a standard 10 min dynamic warm-up. The dynamic warm-up included 1min of light jogging, 10 stationary body weight squats, 10m walking lunge, and dynamic stretches of the hip, thigh and calf muscles. After the COD test, athletes were then performed IMTP testing.

Change of Direction (COD) test

A modified 505 COD test was used to evaluate athletes' COD performance (Figure 4.1). Athletes were required to sprint 5m, perform a 180° turn and sprint back to the starting line. Each athlete performed two familiarization trials for each leg at about 50% and 75% of perceived maximal effort. A total of 4 maximal effort trials were recorded, following the order of left, right, left, and right (two trials performed cutting with left leg, and two trials with right leg), with 1 min rest between each trial. Two sets of timing gates were used to assess athletes' 3m acceleration time (3mAcc), total time (TT) and partial time (PT). PT was calculated by subtracting athletes' 3mAcc by their TT. The average of two testing trials was

used for statistical analysis. Asymmetries between left and right sides COD performance were also calculated as a symmetry index (SI) score, the details of the SI score calculation will be described in the SI calculation section.

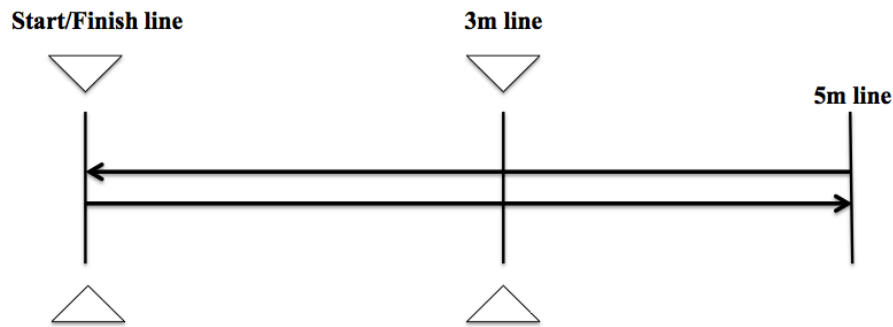


Figure 4.1. Schematic approach of COD test

Isometric Mid-Thigh Pull (IMTP) test

Assessment of bilateral force production asymmetry was conducted with IMTP test. The standard protocol was based on a previous study (Bailey et al., 2013). Unilateral strength characteristics were tested on a dual force plate built into a customized rack (Figure 4.2). Prior to the testing, subjects used weightlifting straps and were taped to the immovable bar to ensure the grip strength was not the limiting factor while performing a maximal effort. Bar height was adjusted to each individual's knee angle at $125^{\circ} \pm 5^{\circ}$ and hip was at $175^{\circ} \pm 5^{\circ}$ (Figure 4.3). This position has been shown to produce the highest peak force (Beckham et al., 2013). Two warm-up trials at approximately 50% and 75% of maximal effort were then performed. Two maximal pulls were measured. The duration for each trial was approximately 3 to 4 sec with 2 min rest between trials. Data from 2 trials were averaged prior to statistical analysis. Isometric peak force (IPF), and instantaneous forces at 50, 90 and 250ms (F50, F90 and F250) from each force plate were used to calculate SI scores. Again, the method of SI score calculation will be listed in the next section. The side that produced higher IPF during IMTP test was defined as the SD side. A customized LabView10.0 software program (National

Instruments Co., Austin, TX) was utilized to analyze force-time data. A digitized signal was filtered using a 4th order Butterworth low-pass filter at 100 Hz.



Figure 4.2. Dual force plate set up



Figure 4.3. IMTP test

Symmetry index (SI) score calculation

According to Sato and Heise (2012), the symmetry index (SI) score was calculated as: $SI = (\text{larger value} - \text{smaller value}) / \text{total value} * 100$. The result of SI score is presented as percentage, in which 0% means perfect symmetry. The higher the value away from zero also indicates the increase of asymmetry. In order to compare the effects of bilateral strength asymmetry on COD test. Subjects with IPF SI scores over 6 % were included in more asymmetrical group. On the other hand, IPF SI scores less than 4% were put into less asymmetrical group. If subjects' IPF SI scores ranged from 4.01 and 5.99%, they were excluded from statistical analysis to separate two groups (Sato & Heise, 2012). No outliers were found in the more asymmetrical group, all subjects in this group displayed SI scores < 10%. SI scores from COD and IMTP tests were calculated using absolute values to represent the magnitudes of asymmetry.

Statistical analysis

The intraclass correlation coefficient (ICC) and coefficient of variation (CV) were calculated to determine the test-retest reliability of the COD and IMTP tests. The relationships between COD and IMTP SI scores were assessed using Pearson's product

moment correlations. The strength of relationship was based on Hopkins (2002), in which $r \leq 0.30$ is moderate; $r \leq 0.50$ is strong; $r \leq 0.70$ is very strong; $r \leq 0.90$ is nearly perfect; $r \leq 1.00$ is perfect. Paired samples t -test was used to determine whether significant differences between SD and NSD sides during COD tests. Additional independent samples t -test was used to evaluate whether less asymmetry group ($n = 11$) had better COD performance than more asymmetry group ($n = 11$). Cohen's effect sizes (d) were also calculated. The magnitude of effect sizes are described by Cohen (1988) as small ($d \leq 0$ to 0.19), moderate ($d = 0.2$ to 0.8), and large ($d \geq 0.8$). Statistical significance was set at an alpha level of $P \leq 0.05$. SPSS software 21.0 version was used to analyze all statistical calculation (IBM Co., NY, USA).

Results

The test-retest reliability for COD test variables ICC are between 0.87 to 0.95, and CV are between 5.7 % to 8.0 %. Further, the reliability for all IMTP test variables are ICCs ≥ 0.96 , and CVs are $\leq 3\%$. Table 4.1 displayed the relationships between IMTP and COD tests SI scores. Moderate to strong statistical significance was found between F50 and PT ($r = 0.42$), F90 and PT ($r = 0.60$). The comparisons between SD and NSD side are showed in Table 4.2. There is no significant differences were found ($p > 0.05$). Additional comparisons between more asymmetry group (IPF SI $\geq 6\%$) and less asymmetry group (IPF SI $\leq 4\%$) in COD performance are also revealed in Table 4.3. Again, there was no statistical differences were discovered between these two groups on COD performance ($p > 0.05$).

Table 4.1. The relationships between IMTP SI score and COD SI score

	IPF	F50	F90	F250
3mA	-0.13	0.00	0.12	-0.20
PT	0.12	0.42*	0.60**	0.20
TT	0.03	0.23	0.38	0.23

Note: * $p < 0.05$, ** $p < 0.01$, IMTP= Isometric mid-thigh pull, SI= symmetry index, COD= change of direction.

Table 4.2. Comparison of COD performance between the SD and NSD sides. (Mean \pm SD).

	SD side	NSD side	<i>P</i>	ES
3mA (s)	0.90 \pm 0.07	0.90 \pm 0.08	0.95	0.00
PT (s)	2.88 \pm 0.16	2.97 \pm 0.16	0.48	0.06
TT (s)	2.02 \pm 0.27	2.00 \pm 0.27	0.43	0.07

Note: COD= change of direction, SD= strength dominant, NSD= non-strength dominant, 3mA= 3m approach time, PT= partial time, TT= Total time.

Table 4.3. Comparison of COD performance between the more asymmetric group and less asymmetric groups. (Mean \pm SD).

	More asymmetrical (N=11, IPF SI e 6 %)	Less asymmetrical (N=11, IPF SI d 4 %)	<i>p</i>	ES
3mA left (s)	0.88 \pm 0.07	0.91 \pm 0.08	0.33	0.41
3mA right (s)	0.86 \pm 0.07	0.90 \pm 0.05	0.12	0.66
PT left (s)	1.96 \pm 0.13	1.95 \pm 0.11	0.84	0.08
PT right (s)	1.97 \pm 0.13	1.95 \pm 0.10	0.64	0.19
TT left (s)	2.84 \pm 0.17	2.86 \pm 0.10	0.72	0.15
TT right (s)	2.83 \pm 0.17	2.85 \pm 0.14	0.74	0.13

Note: COD= change of direction, IPF= Isometric peak force, SI= symmetry index, 3mA= 3m approach time, PT= partial time, TT= Total time.

Discussion

The primary purpose of this study was to evaluate whether bilateral strength asymmetry during IMTP was correlated to asymmetry during COD performance. Results revealed that F50 and F90 SI score was moderately to strongly related to PT SI scores ($r = 0.42$ to 0.60). This indicates that athletes possessing more force production asymmetry during IMTP at 50ms and 90ms were more likely to perform asymmetrically during COD test. According to (Castillo-Rodríguez et al., 2012), PT may be the most important variable in the whole COD task because it assesses subjects' ability to brake and re-acceleration in a short

time. It could be speculated that the ability to generate force in a short period of time might influence subjects' re-acceleration ability. It seems intuitive that it would be beneficial for soccer athletes to perform superiorly in COD related tasks in all directions, and based on the correlation results of the current study, the ability to do this may be influenced by bilateral strength asymmetries in early force production

This is the first study to explore the relationships of SI scores between IMTP and COD tests. However, SI scores in this study were calculated in absolute values that only represent the magnitude of the level of asymmetry, not the direction. As the purpose of this preliminary investigation was to discover the interrelations of asymmetry levels between two the different tests, the authors cannot determine if the bilateral strength asymmetry actually caused the performance differences during COD test, or vice versa. As a result, further research is needed

It has been shown that the D side had superior performance during a COD task (Castillo-Rodríguez et al., 2012; Hoffman et al., 2007). However, the existing literature has not established objective criteria to differentiate between D and ND sides during COD tasks Spiteri et al. (2013) reported that stronger athletes generated higher braking forces, and propulsive forces on their D side during a plant phase in a COD test. In this study, dominance was defined as the side that produced higher IPF during IMTP test, which was then compared to the NSD sides on COD test variables. Interestingly, the SD did not show the significant performance differences on 3mA, PT and TT ($p > 0.05$). Furthermore, the Cohen's effect sizes also revealed a small effect sizes ($ES = 0.00$ to 0.07). It appears that strength dominance does not markedly affect the COD performance in collegiate soccer athletes.

Previous studies have discussed the asymmetry level and its effects on the performance outcomes (Hart et al., 2014; Hoffman et al., 2007; Sato & Heise, 2012).

Sato and Heise (2012) demonstrated that subjects with WtD asymmetry of 6% or more were likely to perform with excessive barbell tilt and rotation during squatting exercises. Hart et al. (2014) found accurate kickers had significant less asymmetry in lean mass and strength of their lower limbs than inaccurate kickers. In the COD related studies, Hoffman et al. (2007) have reported that a significant difference ($p < 0.05$) in unilateral jump power did not cause performance differences on COD performance between D and ND legs. The current study displays similar results as previously reported. There were no statistically significant differences found between the more asymmetric group (IPF SI $\geq 6\%$) and the less asymmetric group (IPF SI $\leq 4\%$). Although Cohen's effect sizes showed a moderate effect on 3mA left and 3mA right (ES = 0.41 and 0.66), 3mA time in the COD test only represents subjects' initial acceleration ability, not the whole COD performance. This phenomenon may also be illustrated by the small effect sizes on PT and TT (ES = 0.08 to 0.19). Although moderate to strong relationships were observed between performance asymmetries of PT and instantaneous forces (F50 and F90), based on the comparison results, bilateral strength asymmetry does not appear to be an influential factor on collegiate soccer athletes' COD performance. It is important to note that samples were split based upon IPF SI scores. Splitting samples based upon F50 or F90 SI scores might have produced different results.

In summary, we found the SI scores at F50 and F90 from an IMTP test were related to PT SI scores during COD test, suggesting that those with more asymmetry occurring during IMTP test were more likely to have larger asymmetry outcome in the COD test. Furthermore, the SD leg during IMTP test did not produce better COD performance. In addition, the apparently greater asymmetry occurring during the IMTP test (IPF SI $> 6\%$) did not appear to be a limiting factor in the COD test.

References

- Beckham, G., Mizuguchi, S., Carter, C., Sato, K., Ramsey, M., Lamont, H., . . . Stone, M. (2013). Relationships of isometric mid-thigh pull variables to weightlifting performance. *Journal of Sports Medicine and Physical Fitness*, 53(5), 573-581.
- Bailey, C., Sato, K., Alexander, R., Chiang, C. Y., & Stone, M. H. (2013). Isometric force production symmetry and jumping performance in collegiate athletes. *Journal of Trainology*, 2, 1-5.
- Bazyler, C. D., Bailey, C., Chiang, C. Y., Sato, K., & Stone, M. H. (2014). The effects of strength training on isometric force production symmetry in recreationally trained males. *Journal of Trainology*, 3, 6-10.
- Bell, D. R., Sanfilippo, J., Binkley, N., & Heiderscheit, B. C. (2014). Lean mass asymmetry influences force and power asymmetry during jumping in collegiate athletes. *Journal of Strength and Conditioning Research*. doi: 10.1519/JSC.0000000000000367
- Castillo-Rodríguez, A., Fernández-García, J., Chinchilla-Minguet, J., & Carnero, E. Á. (2012). Relationship between muscular strength and sprints with changes of direction. *The Journal of Strength & Conditioning Research*, 26(3), 725-732. doi: 10.1519/JSC.0b013e31822602db.
- Chaouachi, A., Manzi, V., Chaalali, A., Wong del, P., Chamari, K., & Castagna, C. (2012). Determinants analysis of change-of-direction ability in elite soccer players. *Journal of Strength and Conditioning Research*, 26(10), 2667-2676. doi: 10.1519/JSC.0b013e318242f97a
- Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2 ed ed.). Hillsdale: Lawrence Erlbaum Associates.

- Hart, N. H., Nimphius, S., Spiteri, T., & Newton, R. (2014). Leg strength and lean mass symmetry influences kicking performance in Australian Football. *Journal of Sports Science and Medicine*, 13(1), 157-165.
- Henry, G. J., Dawson, B., Lay, B. S., & Young, W. B. (2013). Relationships between reactive agility movement time and unilateral vertical, horizontal and lateral jumps. *Journal of Strength and Conditioning Research*, (ahead-of-print).
- Hewit, J. K., Cronin, J. B., & Hume, P. A. (2012). Asymmetry in multi-directional jumping tasks. *Physical Therapy in Sports*, 13(4), 238-242. doi: 10.1016/j.ptsp.2011.12.003
- Hoffman, J. R., Ratamess, N. A., Klatt, M., Faigenbaum, A. D., & kang, J. (2007). Do bilateral power deficits influence direction-specific movement patterns? *Research in Sport Medicine* 15(2), 125-132.
- Hopkins, W. (2002). A scale of magnitudes for effect statistics. Available from URL: www.sportsci.org/resource/stats/effectmag.html
- Meylan, C., McMaster, T., Cronin, J., Mohammad, N. I., Rogers, C., & Deklerk, M. (2009). Single-leg lateral, horizontal, and vertical jump assessment: reliability, interrelationships, and ability to predict sprint and change-of-direction performance. *Journal of Strength and Conditioning Research*, 23(4), 1140-1147. doi: 10.1519/JSC.0b013e318190f9c2
- Sato, K., & Heise, G. D. (2012). Influence of weight distribution asymmetry on the biomechanics of a barbell back squat. *Journal of Strength and Conditioning Research*, 26(2), 342-349. doi: 10.1519/JSC.0b013e318220e0a3
- Spiteri, T., Cochrane, J. L., Hart, N. H., Haff, G. G., & Nimphius, S. (2013). Effect of strength on plant foot kinetics and kinematics during a change of direction task. *European Journal of Sport Science*, 13(6), 646-652.

Young, W. B., James, R., & Montgomery, I. (2002). Is muscle power related to running speed with changed of direction? *Journal of Sports Medicine and Physical Fitness*, 42(3), 282-288.

CHAPTER 5

STUDY III

Title: An investigation into kinetics factors comparisons during a change of direction task in male and female college soccer players: An exploratory study

AUTHORS: Chieh-Ying. Chiang, Christopher A. Bailey, Kimitake Sato, Michael W. Ramsey, G. Gregory Haff, Michael H. Stone

Paper prepared for submission to *International Journal of Sports Medicine*

Abstract

Although the relationships between the force production ability and change of direction (COD) performance have been examined, the sex differences of kinetic contributions during the stance phase of cutting in COD performance are still unknown. This study aimed to compare kinetic variables between sexes, as well as to determine the critical factors of performance during a COD test. Twenty-four NCAA Division I soccer athletes participated in this study (11 male and 13 female; age, male = 21.37 ± 1.94 y, female = 21.29 ± 0.99 y; body mass, male = 78.31 ± 8.92 kg, female = 65.76 ± 5.83 kg). A modified 505 COD test was used to assess athletes' COD ability. Kinetic variables included ground contact time (GCT), forces and impulse in two phases (braking and propulsive) and two directions (vertical and horizontal) were recorded. A significantly shorter COD total time was discovered in male athletes ($p < 0.01$, ES = 2.17). Furthermore, male athletes had statistically higher horizontal braking impulse ($p = 0.04$, ES = 0.88), vertical braking impulse ($p < 0.01$, ES = 1.20), total vertical impulse ($p = 0.02$, ES = 0.97) and significantly longer GCT. In summary, male athletes demonstrated less COD total time, longer GCT and better ability to apply forces and impulse while performing a cutting maneuver during a modified 505 COD test compared to females. Furthermore, the vertical forces and impulse appear to be the limiting factors for COD tasks.

Key words: soccer, agility, team sports, kinetic

Introductions

Agility has been proposed as one of the most important aspects of fitness for talent identification in soccer (Reilly, Williams, et al., 2000). Considering athletes' overall agility performance, change of direction (COD) ability and the perceptual and decision-making components have been examined and reported as two major limiting factors (Sheppard & Young, 2006; Sheppard et al., 2006). Recently, the physical contributions of COD ability, such as leg strength, power and sprint speed, have been evaluated across different sports. (Barnes et al., 2007; Castillo-Rodríguez et al., 2012; Chaouachi et al., 2012; Nimphius et al., 2010)

Barnes et al. (2007) found vertical jump height can be used for predicting female volleyball athletes' COD performance. In this study, NCAA division I female volleyball players showed superior vertical jump heights compared to division II and division III level players (Barnes et al., 2007). Nimphius et al. (2010) reported that the ability to generate power under loaded vertical jumps was negatively correlated to COD time in a group of national level softball players ($r = -0.75$ to -0.85). Similar results were found by Castillo-Rodríguez et al. (2012) who found both countermovement jumps (CMJs) and drop jumps (JPs) were negatively related to soccer players' COD performance. Consequently, it appears to be critical for athletes to produce high force and power during COD tasks. However, it is relatively unknown which kinetic factors may affect the final outcome while performing the cutting during COD tasks.

The relationship of direct measures of kinetic variables of cutting measured during COD tasks to performance outcomes have not been well established in the literature. A study by Green, Blake, and Caulfield (2011a) examined the kinetic characteristics during 45° turn COD test in semi-professional rugby players. They found starters had statistically shorter ground contact time (GCT) than non-starters. Sasaki, Nagano, Kaneko, Sakurai, and

Fukubayashi (2011) reported a positive correlation between GCT and COD total time ($r = 0.42$) during a 180° turn COD test, indicating athletes who had shorter GCT were able to perform the COD test better. Similar results were reported by Marshall et al. (2014). Moreover, stronger athletes who had higher peak force during a unilateral isometric strength test demonstrated faster post- COD strides, and higher forces and impulses in both vertical and horizontal directions during the stance phase. (Spiteri et al., 2013). Thus, kinetic factors that related to athletes' COD performance were deemed to be important information for the strength and conditioning field. Finally, very few studies have examined the performance differences in COD tasks between sexes.

Therefore, the main purpose of this study was to compare kinetic variables during a COD test between sexes to determine if sex differences in those variables could affect the final COD performance outcome. Additionally, force and impulse applied in both vertical and horizontal directions were also calculated to assess dominance of either during the COD task.

Methods

Participants

Twenty-four soccer ($n = 11$ male and 13 female) athletes who competed in NCAA Division I level participated in this study. Athletes' age, height and body mass from both sexes are displayed in Table 1. Data collection was part of a long-term athletes monitoring program at East Tennessee State University (ETSU). All participants read and signed informed consent documents that were approved by the university's Institutional Review Board. All participants in this study were injury free for at least 6 months prior to the experiment.

Warm-up

A series of dynamic warm-up exercises were implemented prior to the COD test. The dynamic warm-up included 1min of light jogging, 10 stationary body weight squats, 10m walking lunge, and dynamic stretches of the hip, thigh and calf muscles. The warm-up sessions were supervised by a certified strength and conditioning specialist to insure all participants were performing those exercises properly.

Change of direction (COD) test

A modified 505 COD test was used to evaluate soccer athletes' COD performance. The test was completed on a 6×1 m customized running platform with a built-in AMTI tri-axial force plate (AccuPower; Watertown, MA) (Figure 5.1). The force plate was operated by a laptop (Dell, Texas, USA) and sampled at 400 Hz for data collection. Two sets of timing gates (Brower timing system; Utah, USA) were set up at starting/finish line and 3m line, in order to measure 3m approach speed and total time of the COD test. The 3m approach speed was controlled at $3.5 \pm 0.5 \text{ m}\cdot\text{s}^{-1}$ to assure that velocity variations did not contribute to the differences in kinetic factors between sexes (Spiteri et al., 2013). Athletes started with staggered stand position at the starting line. The COD test protocol was conducted with modified method from Barnes et al. (2007) where athletes put their toe of the lead leg 30cm behind the line, mimicking the most common starting position in a game situation. Athletes were asked to sprint 5m, stepping on the force plate, performing a cutting with a 180° turn and sprinting back until passing the finishing line. Two sub-maximal familiarization trials at 50 % and 75% effort were performed with for both left and right foot cutting. Four maximal effort trials were performed in the following order: left, right, left right (two trials with left foot stepping on the force plate, the other two with right foot) were measured after 2 min rest from familiarization trials. Each trial was separated by a 1min recovery period. During maximal effort trials, athletes were required to contact their whole foot on the force plate by

performing a side step cutting maneuver only (Besier, Lloyd, & Ackland, 2003). The trials were excluded if athletes were not successful in planting their foot on the force plate or slipped during the test. Measurements were sustained until four successful trials were recorded (Sasaki et al., 2011).

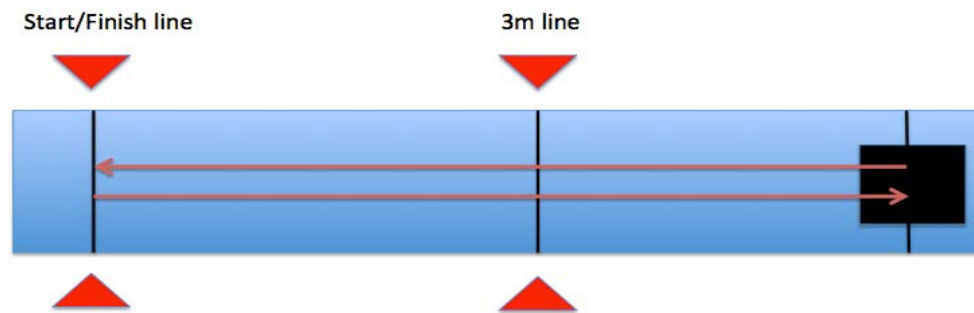


Figure 5.1. Schematic approach of COD test set up

Kinetic measurement

In order to compare the sex differences of the COD test, two best trials (shortest of COD total time) were used for data analysis. Ground reaction forces (GRFs) and impulse from both vertical and horizontal orientations were recorded over the stance phase during the COD cutting movement. The stance phase has been defined by McLean et al. (2004), as where the heel strike is described as the instant vertical GRF is in excess of 10N, and toe off is described as the instant GRF falls below 10N. Variables used for statistical comparisons in this study were GCT, braking phase GCT, propulsive phase GCT, peak braking force, peak propulsive force, braking impulse, propulsive impulsive and total impulse. The calculations of braking force and impulse in this study was defined as heel strike to minimum vertical GRF of the middle-support phase, and propulsive barking force and impulse were calculated from the minimum middle-support phase to toe-off (Spiteri et al., 2013). Total horizontal impulse was computed by calculating the resultant force vector of medio-lateral and anterior-posterior force- time curves. All kinetic variables were calculated using a customized LabView10.0 software program (National Instruments Co., Austin, TX). A digital low pass Butterworth filter with a cutoff frequency of 10 Hz was used to remove electrical noise. The

comparisons of all forces and impulses between sexes were calculated with data that was allometrically scaled [absolute force and impulse \cdot body mass^{-0.67}] (Jaric, 2002).

Statistical analysis

The intraclass correlation coefficients (ICC) with 95% confidence intervals (CI) and coefficient of variations (CV) were calculated to determine the test-retest reliability of all COD test variables. A series of independent samples *t*-tests were used to compare sex differences on athletes' anthropometric variables (age, height and body mass) and COD test variables. Cohen's effect sizes estimates (*d*) were also calculated. The magnitudes of effect sizes are described by Cohen (1988) as small (*d* d 0 to 0.19), moderate (*d* = 0.2 to 0.8), and large (*d* e 0.8). Statistical significance of comparison analysis was set at an alpha level at $P < 0.05$. SPSS software 21.0 version was used to analyze all statistical calculation (IBM Co., NY, USA).

Results

The test-retest reliability from COD test variables are displayed in Table 5.1, which ICCs (95% CI) ranged from 0.76 to 0.96, and CVs were between 5.90% and 26.36%. Statistical differences were found between sexes in height and body mass ($p < 0.01$), which are shown in Table 5.2. The comparison results of COD total time, GCT, forces and impulses are revealed in Table 5.3, Figure 5.2 and Figure 5.3. Male athletes produced significantly shorter COD total time than female athletes ($p < 0.01$, ES= 2.17). No statistical difference was found for total GCT between sexes; however, significantly longer braking GCT was shown in male athletes (male = 0.27 ± 0.05 , female = 0.22 ± 0.05 ; $p = 0.04$, ES= 0.88). Male athletes also displayed significantly higher horizontal braking impulse ($p = 0.04$, ES= 0.88), vertical braking impulse ($p < 0.01$, ES= 1.20), and vertical total impulse ($p = 0.02$, ES= 0.97) (Figure 5.3.). Although statistical differences in horizontal total impulse ($p = 0.22$) and vertical braking impulse ($p = 0.05$) were observed between sexes, moderate to strong effect

sizes of 0.51 to 0.86 were achieved (Table 5.3). The magnitudes of vertical forces and impulses from both sexes ranged from 2.51 to 3.14 times larger than horizontal forces and impulses, which were revealed in Table 5.4.

Table 5.1. Test-retest reliability base on ICC and CV for COD total time, force and impulse variables

	ICC (95% CI)	CV (%)
COD total time	0.96 (0.92-0.97)	5.90
GCT	0.86 (0.58-0.94)	7.64
GCT (Braking)	0.82 (0.52-0.92)	16.68
GCT (Propulsive)	0.76 (0.53-0.90)	17.17
H peak braking force	0.86 (0.67-0.94)	18.25
H peak propulsive force	0.89 (0.63-0.93)	14.72
H braking impulse	0.82 (0.56-0.92)	24.37
H propulsive impulse	0.84 (0.60-0.93)	22.74
H total impulse	0.88 (0.77-0.94)	19.92
V peak braking force	0.87 (0.70-0.94)	16.87
V peak propulsive force	0.96 (0.94-0.98)	17.53
V braking impulse	0.86 (0.66-0.94)	26.36
V propulsive impulse	0.83 (0.50-0.91)	24.83
V total impulse	0.90 (0.81-0.95)	17.56

ICC = intraclass correlation coefficient, CI= confidence interval, COD = change of direction, CV = coefficient of variation, GCT = ground contact time, H = horizontal, V = vertical

Table 5.2. Descriptive statistics of athlete' age, height and body mass (Mean \pm SD)

	Male (n= 11)	Female (n= 13)
Age (year)	21.37 \pm 1.94	21.29 \pm 0.99
Height (cm)	179.87 \pm 6.79**	168.30 \pm 6.86**
Body mass (kg)	78.31 \pm 8.92**	65.76 \pm 5.83**

**
 $p < 0.01$

Table 5.3. Comparisons of sex differences in COD total time, force and impulse variables (mean \pm SD)

	Male (n= 11)	Female (n= 13)	<i>p</i>	ES
COD total time (s)	2.69 \pm 0.09	2.93 \pm 0.12 ^{**}	0.00	2.17
GCT (Total)(s)	0.54 \pm 0.08	0.48 \pm 0.06	0.09	0.70
GCT (Braking) (s)	0.27 \pm 0.05	0.22 \pm 0.05 [*]	0.04	0.88
GCT (Propulsive) (s)	0.26 \pm 0.05	0.26 \pm 0.03	0.81	0.09
H peak braking force (N·kg ^{-0.67})	21.90 \pm 3.55	21.69 \pm 3.01	0.87	0.06
H peak propulsive force (N·kg ^{-0.67})	18.24 \pm 2.67	18.69 \pm 2.55	0.44	0.30
H braking impulse (N·s·kg ^{-0.67})	4.28 \pm 1.17	3.37 \pm 0.85 [*]	0.04	0.88
H propulsive impulse (N·s·kg ^{-0.67})	3.27 \pm 0.88	3.52 \pm 0.67	0.44	0.30
H total impulse (N·s·kg ^{-0.67})	7.55 \pm 1.46	6.89 \pm 1.09	0.22	0.51
V peak braking force (N·kg ^{-0.67})	56.58 \pm 2.62	53.05 \pm 5.15	0.05	0.86
V peak propulsive force (N·kg ^{-0.67})	56.78 \pm 4.06	54.69 \pm 5.35	0.30	0.43
V braking impulse (N·s·kg ^{-0.67})	11.64 \pm 2.72	8.50 \pm 2.44 ^{**}	0.00	1.20
V propulsive impulse (N·s·kg ^{-0.67})	10.77 \pm 2.59	10.66 \pm 1.73	0.90	0.05
V total impulse (N·s·kg ^{-0.67})	22.41 \pm 3.64	19.17 \pm 3.02 [*]	0.02	0.97

COD = change of direction, GCT = ground contact time, H = horizontal, V = vertical, ES = effect size. * $p < 0.05$, ** $p < 0.01$

Table 5.4. Descriptive statistics of horizontal and vertical force and impulse variables (mean \pm SD)

	Horizontal	Vertical
Peak braking force (N's ⁻¹)	373.01 \pm 67.18	937.41 \pm 131.02
Peak propulsive force (N's ⁻¹)	316.35 \pm 54.63	954.22 \pm 28.26
Braking impulse (N's ⁻¹)	65.51 \pm 22.48	172.20 \pm 60.82
Propulsive impulse (N's ⁻¹)	58.25.27 \pm 14.08	183.43 \pm 40.77

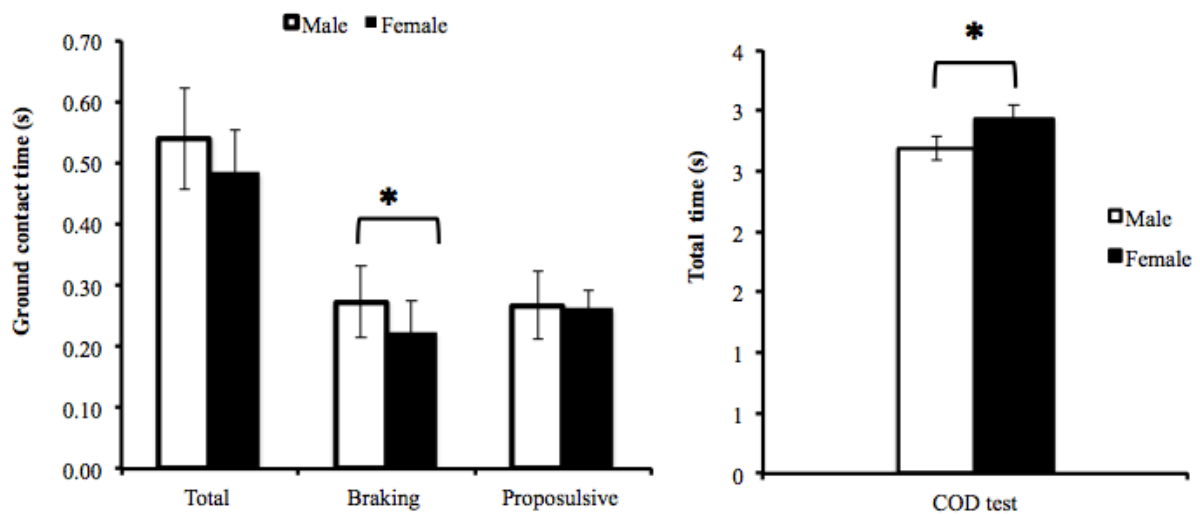


Figure 5.2. Comparison of ground contact time and COD test total time between male and female soccer athletes

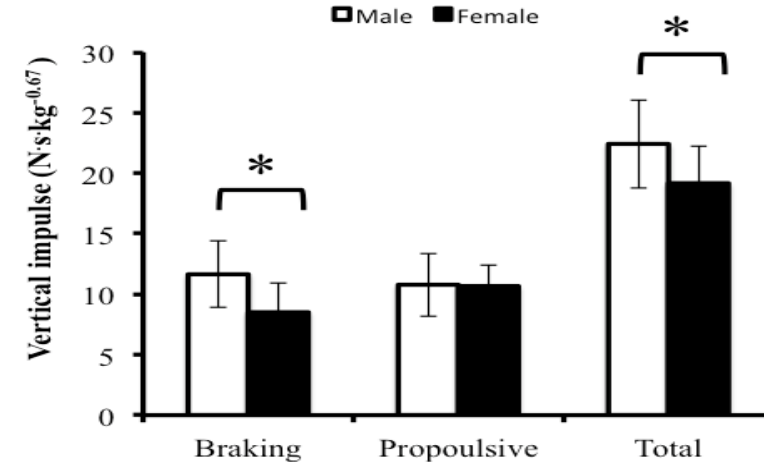
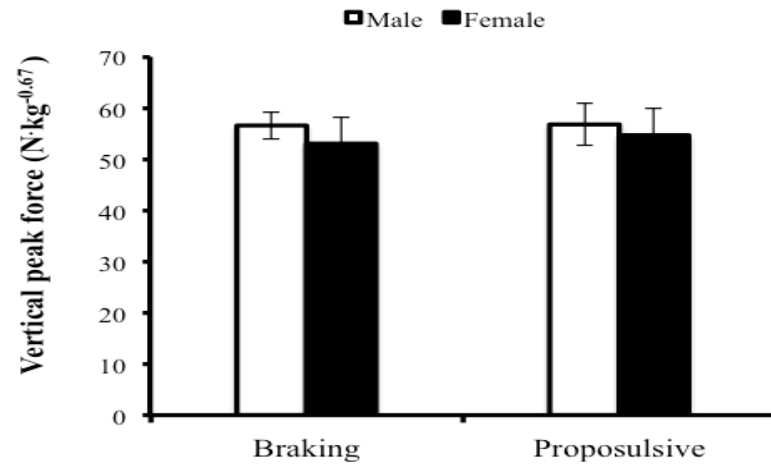
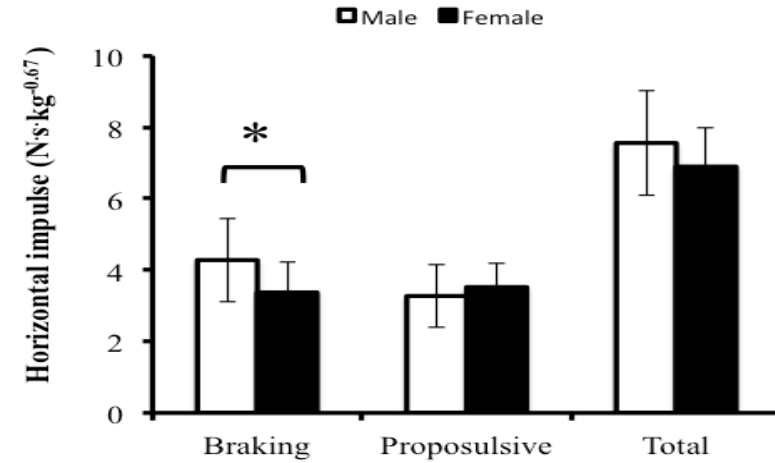
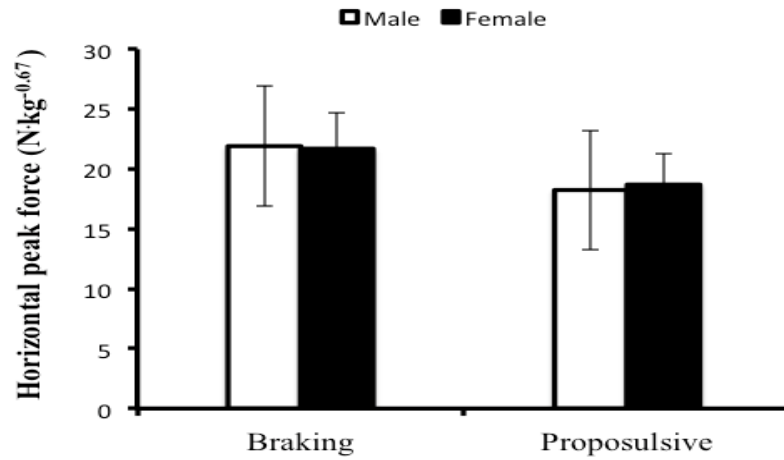


Figure 5.3. Comparisons of force and impulse variable between sexes; Left top: peak horizontal forces: braking and propulsive; Right top: horizontal impulses: braking, propulsive and total; Left bottom: peak vertical forces: braking and propulsive; Right bottom: vertical impulses: braking, propulsive and total.

Discussion

The primary purpose of this investigation was to determine if sex differences exist in both vertical and horizontal force and impulse variables during a COD test, as well as to determine the importance of vertical and horizontal GRFs and impulse involved in the COD test. The primary findings of this study reveal that male soccer athletes were able to perform better in COD test, while also producing higher horizontal braking impulse, vertical impulse and vertical total impulse when compared to female soccer athletes. Moreover, vertical forces and impulses were 2.51 to 3.14 times higher while compared to horizontal forces and impulses. This result indicates that the majority forces and impulses involved in a 180° turning COD task were vertically oriented, which is consistent with previously published data indicating that vertical GRFs and impulses could be considered as limiting factors in COD tasks (Barnes et al., 2007).

The ICC levels of kinetic variables in the COD test ranged from 0.76 to 0.96. According to Portney and Watkins (2000) that ICC higher than 0.75 could be considered as good test-retest reliability. The reliability of GCT (ICC = 0.86) from this study is consistent with previously reported research by Green et al. (2011a) (ICC = 0.89 to 0.96) and Marshall et al. (2014) (ICC > 0.76). However, higher CVs from kinetic variables were also discovered (16.7% to 24.8%), except for CV of COD total time (5.9%) and GCT (7.6%). Similar results reported by Wong, Chaouachi, Dellal, and Smith (2012) who found high CV (14.5% to 67.9%) of forces and impulses from a leg hopping exercise, which mimicked the stance phase of common COD tasks. The high CV may be caused from the different techniques being used in both braking and propulsive phases (Wong et al., 2012).

Recently, the relationships between GCT and COD performance have been discussed (Green et al., 2011a; Marshall et al., 2014; Sasaki et al., 2011; Wong et al., 2012). Green et al. (2011a) found starters had significant shorter GCT compared to non-starters. Sasaki et al.

(2011) also reported that GCT was correlated to COD total time ($r = 0.44$) in a group of male college soccer athletes. Based on Sasaki et al. (2011), it seems that those with shorter GCT during the stance phase of a COD task were more likely to perform better in the COD total time. Interestingly, the findings of this study were contrary from the aforementioned. Male athletes demonstrated significantly longer GCT during the braking phase than female athletes ($P = 0.04$, $ES = 0.88$). Although no statistical difference was observed in total GCT, moderate effect size ($ES = 0.70$) suggests that male athletes had longer total GCT (male = 0.54 ± 0.08 , female = 0.48 ± 0.06). Moreover, male athletes demonstrated statistically significantly shorter COD total time than female athletes (male = 2.69 ± 0.09 , female = 2.93 ± 0.12). Thus, shorter total GCT may not be the limiting factor for COD performance while comparing sex differences.

It has been recognized that the ability to produce force rapidly is associated with athletes' COD performance (Nimphius et al., 2010; Spiteri et al., 2013). A recent study by Spiteri et al. (2013) found stronger athletes were able to produce statistically higher braking and propulsive GRFs in both vertical and horizontal directions. In this study, no statistical between sex differences were shown in both braking and propulsive GRFs, which were calculated as allometrically scaled. However, large effect size ($ES = 0.86$) was discovered in vertical braking force, suggesting male athletes generated higher GRFs during the braking phase when compared to female athletes. Impulse application, especially braking impulse has been shown to be an underlying mechanism for utilizing elastic energy during sprinting, consequently increasing force output for the propulsive phase (Hunter, Marshall, & McNair, 2005). This study indicates that male athletes applied significantly higher horizontal braking impulse, vertical braking impulse and total vertical impulse than female athletes. Therefore, the ability to produce higher forces and impulses, especially during braking phase appears to affect the subsequent COD performance. Although lower extremity strength was not

measured in this study, a previous study reported that stronger athletes applied significantly higher forces and impulses during both braking and propulsive phases than their weaker counterparts, leading them to superior COD performance (Spiteri et al., 2013). Further research is needed to distinguish which strength characteristics (concentric, eccentric and isometric) contribute to the force and impulse application during COD tasks.

In order to maximize COD performance, coaches and strength and conditioning professionals often train their athletes with lateral movements. This training methodology is commonly used due to its apparent movement similarity. However, results in the current study clearly showed that forces and impulses in the vertical direction were more dominant than those in the horizontal when performing a COD movement required athletes to turn their positions laterally. This finding is in agreement with Barnes et al. (2007) who found that vertical forces were two times higher than horizontal forces in a COD task. Therefore, it is reasonable for athletes and coaches who want to improve COD performance by training vertically oriented exercises such as squat and weightlifting movements and their derivatives (Sheppard & Young, 2006). In conclusion, the present study found that male athletes demonstrated significantly shorter COD total time. Furthermore, male athletes had significantly longer GCT during braking phase as well as significantly higher horizontal braking impulse, vertical braking impulse and total vertical impulse than female athletes while performing a cutting in a modified 505 COD test. Based on the results, the vertical forces and impulses appear to be the primary limiting factor during the COD test.

References

- Barnes, J. L., Schilling, B. K., Falvo, M. J., Weiss, L. W., Creasy, A. K., & Fry, A. C. (2007). Relationship of jumping and agility performance in female volleyball athletes. *Journal of Strength and Conditioning Research*, 21(4), 1192-1196. doi: 10.1519/R-22416.1
- Besier, T. F., Lloyd, D. G., & Ackland, T. R. (2003). Muscle activation strategies at the knee during running and cutting maneuvers. *Medicine and Science in Sports and Exercise*, 35(1), 119-127. doi: Doi 10.1249/01.Mss.0000043608.79537.Ab
- Castillo-Rodríguez, A., Fernández-García, J., Chinchilla-Minguet, J., & Carnero, E. Á. (2012). Relationship between muscular strength and sprints with changes of direction. *The Journal of Strength & Conditioning Research*, 26(3), 725-732. doi: 10.1519/JSC.0b013e31822602db.
- Chaouachi, A., Manzi, V., Chaalali, A., Wong del, P., Chamari, K., & Castagna, C. (2012). Determinants analysis of change-of-direction ability in elite soccer players. *Journal of Strength and Conditioning Research*, 26(10), 2667-2676. doi: 10.1519/JSC.0b013e318242f97a
- Green, B. S., Blake, C., & Caulfield, B. M. (2011). A comparison of cutting technique performance in rugby union players. *Journal of Strength and Conditioning Research*, 25(10), 2668-2680. doi: 10.1519/JSC.0b013e318207ed2a
- Hunter, J. P., Marshall, R. N., & McNair, P. (2005). Relationships between ground reaction force impulse and kinematics of sprint-running acceleration. *Journal of Applied Biomechanics*, 21(1), 31-43.
- Marshall, B. M., Franklyn-Miller, A. D., King, E. A., Moran, K. A., Strike, S. C., & Falvey, E. C. (2014). Biomechanical factors associated with time to complete a change of

- direction cutting maneuver. *Journal of Strength and Conditioning Research*. doi: 10.1519/JSC.0000000000000463
- McLean, S. G., Lipfert, S. W., & van den Bogert, A. J. (2004). Effect of gender and defensive opponent on the biomechanics of sidestep cutting. *Medicine and Science in Sports and Exercise*, 36(6), 1008-1016.
- Nimphius, S., McGuigan, M. R., & Newton, R. U. (2010). Relationship between strength, power, speed, and change of direction performance of female softball players. *Journal of Strength and Conditioning Research*, 24(4), 885-895. doi: Doi 10.1519/Jsc.0b013e3181d4d41d
- Reilly, T., Williams, A. M., Nevill, A., & Franks, A. (2000). A multidisciplinary approach to talent identification in soccer. *Journal of Sports Sciences*, 18(9), 695-702. doi: 10.1080/02640410050120078
- Sasaki, S., Nagano, Y., Kaneko, S., Sakurai, T., & Fukubayashi, T. (2011). The relationship between performance and trunk movement during change of direction. *Journal of Sports Science and Medicine*, 10, 112-118.
- Sheppard, J. M., & Young, W. B. (2006). Agility literature review: classifications, training and testing. *Journal of Sports Sciences*, 24(9), 919-932. doi: 10.1080/02640410500457109
- Sheppard, J. M., Young, W. B., Doyle, T. L., Sheppard, T. A., & Newton, R. U. (2006). An evaluation of a new test of reactive agility and its relationship to sprint speed and change of direction speed. *Journal of Science and Medicine in Sport*, 9(4), 342-349. doi: 10.1016/j.jsams.2006.05.019
- Spiteri, T., Cochrane, J. L., Hart, N. H., Haff, G. G., & Nimphius, S. (2013). Effect of strength on plant foot kinetics and kinematics during a change of direction task. *European Journal of Sport Science*, 13(6), 646-652.

Wong, D. P., Chaouachi, A., Dellal, A., & Smith, A. W. (2012). Comparison of ground reaction forces and contact times between 2 lateral plyometric exercises in professional soccer players. *International Journal of Sports Medicine*, 33(8), 647-653.

CHAPTER 6

SUMMARY

The importance of strength and power for athletic movements such as jumping and sprinting has been documented in the literature. However, the relationships between leg strength, power, and COD performance have not been well studied, especially in college soccer athletes. Therefore, the main purpose of this dissertation was to explore the relationships between COD performance and associated physical contributions such as leg strength and power characteristics, straight-line sprinting, bilateral strength asymmetry, and sex differences in kinetic variables among NCAA Division I soccer athletes.

The findings indicate that leg strength and power were moderate to strongly negatively related to the COD TT. In addition, straight-line sprinting was also interrelated with soccer athletes' COD performance. Those results confirmed the hypothesis that athletes are required to produce high force and power in a short period of time ($<250\text{ms}$) in order to perform sudden acceleration, deceleration, and reacceleration during COD tasks. In addition, SJH was able to predict COD TT, suggesting sport scientists and strength and conditioning professionals should use SJs as a monitoring tool in their athletes' performance program.

Although asymmetry in sports had examined the associations with athletes' injury, no study has examined the effects of bilateral strength asymmetry on athletes' COD performance. The findings from this dissertation showed that force production asymmetries during IMTP were related to asymmetrical performance during COD tests. However, it appears that the SD side did not possess better COD performance compared to the NSD side. Furthermore, the magnitude of bilateral strength asymmetry was not the limiting factor for soccer athletes' COD performance outcomes.

A better understanding of force and impulse being applied over the stand phase during cutting is important in providing information regarding the improvement of athletes' COD performance. Male athletes demonstrated a better ability to produce force and impulse than their female counterparts. Consequently, male athletes produced statistically significantly less COD TT and demonstrated longer GCT, higher vertical braking impulses, and total vertical impulses than female athletes. This result may be partly due to more lean muscle mass in lower extremities, which contribute to produce more force and impulse during a cutting maneuver. It may also indicate the different approaches to apply force during cutting between sexes. Ultimately, the magnitude of vertical forces and impulses measured in both sexes was 2.51 to 3.14 times larger than the horizontal direction, indicating that vertical forces and impulses are primary limiting factors while performing in COD tasks.

Future research should emphasize on differentiating strength characteristics such as concentric strength, eccentric strength, and isometric strength and their associations with COD performance in order to identify the critical strength demands associated with different phases in COD movements. Furthermore, the research focus should be on establishing the optimal kinetic and kinematic factors during COD tasks. Longitudinal studies using training intervention in different sexes, sports, and training backgrounds are also warranted. Researchers in this area should focus on comparing different training modalities such as heavy resistant exercises, weightlifting movements, and plyometric exercise that are performed in the vertical orientation in both short terms and long terms to assess the transfer effects on COD performance. Therefore, it is deemed necessary that future investigations focus on this topic.

REFERENCES

- Argus, C. K., Gill, N. D., & Keogh, J. W. L. (2012). Characterization of the differences in strength and power between different levels of competition in rugby union athletes. *Journal of Strength and Conditioning Research*, 26(10), 2698-2704. doi: Doi 10.1519/Jsc.0b013e318241382a
- Bailey, C., Sato, K., Alexander, R., Chiang, C. Y., & Stone, M. H. (2013). Isometric force production symmetry and jumping performance in collegiate athletes. *Journal of Trainology*, 2(1), 1-5.
- Baker, D. G., & Newton, R. U. (2008). Comparison of lower body strength, power, acceleration, speed, agility, and sprint momentum to describe and compare playing rank among professional rugby league players. *Journal of Strength and Conditioning Research*, 22(1), 153-158. doi: Doi 10.1519/Jsc.0b013e31815f9519
- Barnes, J. L., Schilling, B. K., Falvo, M. J., Weiss, L. W., Creasy, A. K., & Fry, A. C. (2007). Relationship of jumping and agility performance in female volleyball athletes. *Journal of Strength and Conditioning Research*, 21(4), 1192-11926. doi: 10.1519/R-22416.1
- Bazyler, C. D., Bailey, C., Chiang, C. Y., Sato, K., & Stone, M. H. (2014). The effects of strength training on isometric force production symmetry in recreationally trained males. *Journal of Trainology*, 3(1), 6-10.
- Beckham, G., Mizuguchi, S., Carter, C., Sato, K., Ramsey, M., Lamont, H., . . . Stone, M. (2013). Relationships of isometric mid-thigh pull variables to weightlifting performance. *Journal of Sports Medicine and Physical Fitness*, 53(5), 573-581.
- Bell, D. R., Sanfilippo, J., Binkley, N., & Heiderscheit, B. C. (2014). Lean mass asymmetry influences force and power asymmetry during jumping in collegiate athletes. *Journal of Strength and Conditioning Research*. doi: 10.1519/JSC.0000000000000367

- Besier, T. F., Lloyd, D. G., & Ackland, T. R. (2003). Muscle activation strategies at the knee during running and cutting maneuvers. *Medicine and Science in Sports and Exercise*, 35(1), 119-127. doi: Doi 10.1249/01.Mss.0000043608.79537.Ab
- Bloomfield, J., Polman, R., & O'Donoghue, P. (2007). Physical demands of different positions in FA Premier League soccer. *Journal of Sports Science and Medicine*, 6(1), 63-70.
- Bompa, T. O., & Haff, G. G. (2009). *Periodization: Theory and methodology of training*. Champaign, IL: Human Kinetics
- Brown, S. R., Griffiths, P. C., Cronin, J. B., & Brughelli, M. (2013). Lower-extremity isokinetic strength profiling in professional rugby league and rugby union. *International Journal of Sports Physiology and Performance*(ahead-of-print).
- Brughelli, M., Cronin, J., Levin, G., & Chaouachi, A. (2008). Understanding change of direction ability in sport: a review of resistance training studies. *Sports Medicine*, 38(12), 1045-1063. doi: 10.2165/00007256-200838120-00007
- Carling, C., Le Gall, F., & Dupont, G. (2012). Analysis of repeated high-intensity running performance in professional soccer. *Journal of Sports Sciences*, 30(4), 325-336. doi: 10.1080/02640414.2011.652655
- Castagna, C., Manzi, V., D'Ottavio, S., Annino, G., Padua, E., & Bishop, D. (2007). Relation between maximal aerobic power and the ability to repeat sprints in young basketball players. *Journal of Strength and Conditioning Research*, 21(4), 1172-1176. doi: Doi 10.1519/00124278-200711000-00032
- Castillo-Rodríguez, A., Fernández-García, J., Chinchilla-Minguet, J., & Carnero, E. Á. (2012). Relationship between muscular strength and sprints with changes of direction. *The Journal of Strength & Conditioning Research*, 26(3), 725-732. doi: 10.1519/JSC.0b013e31822602db.

- Chamari, K., Chaouachi, A., Hambli, M., Kaouech, F., Wisloff, U., & Castagna, C. (2008). The five-jump test for distance as a field test to assess lower limb explosive power in soccer players. *Journal of Strength and Conditioning Research*, 22(3), 944-950. doi: Doi 10.1519/Jsc.0b013e31816a57c6
- Chaouachi, A., Brughelli, M., Chamari, K., Levin, G. T., Ben Abdelkrim, N., Laurencelle, L., & Castagna, C. (2009). Lower limb maximal dynamic strength and agility determinants in elite basketball players. *Journal of Strength and Conditioning Research*, 23(5), 1570-1577. doi: 10.1519/JSC.0b013e3181a4e7f0
- Chaouachi, A., Manzi, V., Chaalali, A., Wong del, P., Chamari, K., & Castagna, C. (2012). Determinants analysis of change-of-direction ability in elite soccer players. *Journal of Strength and Conditioning Research*, 26(10), 2667-2676. doi: 10.1519/JSC.0b013e318242f97a
- Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2 ed.). Hillsdale, NJ: Lawrence Erlbaum Associates.
- Comfort, P., Haigh, A., & Matthews, M. J. (2012). Are changes in maximal squat strength during preseason training reflected in changes in sprint performance in rugby league players? *Journal of Strength and Conditioning Research*, 26(3), 772-776. doi: 10.1519/JSC.0b013e31822a5cbf
- Condello, G., Minganti, C., Lupo, C., Benvenuti, C., Pacini, D., & Tessitore, A. (2013). Evaluation of change-of-direction movements in young rugby players. *International Journal of Sports Physiology and Performance*, 8(1), 52-56.
- Condello, G., Schultz, K., & Tessitore, A. (2013). Assessment of sprint and change-of-direction performance in college football players. *International Journal of Sports Physiology and Performance*, 8(2), 211-212.

- Cormie, P., McGuigan, M. R., & Newton, R. U. (2010). Influence of strength on magnitude and mechanisms of adaptation to power training. *Medicine and Science in Sports and Exercise*, 42(8), 1566-1581. doi: 10.1249/MSS.0b013e3181cf818d
- Cormie, P., McGuigan, M. R., & Newton, R. U. (2011). Developing maximal neuromuscular power Part 1-biological basis of maximal power production. *Sports Medicine*, 41(1), 17-38. doi: Doi 10.2165/11537690-000000000-00000
- Cowley, H. R., Ford, K. R., Myer, G. D., Kernozek, T. W., & Hewett, T. E. (2006). Differences in neuromuscular strategies between landing and cutting tasks in female basketball and soccer athletes. *Journal of Athletic Training*, 41(1), 67-73.
- Cronin, J. B., & Hansen, K. T. (2005). Strength and power predictors of sports speed. *Journal of Strength and Conditioning Research*, 19(2), 349-357. doi: 10.1519/14323.1
- Cunningham, D. J., West, D. J., Owen, N. J., Shearer, D. A., Finn, C. V., Bracken, R. M., . . . Kilduff, L. P. (2013). Strength and power predictors of sprinting performance in professional rugby players. *Journal of Sports Medicine and Physical Fitness*, 53(2), 105-111.
- Faude, O., Koch, T., & Meyer, T. (2012). Straight sprinting is the most frequent action in goal situations in professional football. *Journal of Sports Sciences*, 30(7), 625-631. doi: Doi 10.1080/02640414.2012.665940
- Gabbett, T. J. (2007). Physiological and anthropometric characteristics of elite women rugby league players. *Journal of Strength and Conditioning Research*, 21(3), 875-881. doi: 10.1519/R-20466.1
- Gabbett, T. J., & Benton, D. (2009). Reactive agility of rugby league players. *Journal of Science and Medicine in Sport*, 12(1), 212-214. doi: 10.1016/j.jsams.2007.08.011

- Gabbett, T. J., Kelly, J. N., & Sheppard, J. M. (2008). Speed, change of direction speed, and reactive agility of rugby league players. *Journal of Strength and Conditioning Research*, 22(1), 174-181. doi: 10.1519/JSC.0b013e31815ef700
- Gabbett, T. J., Sheppard, J. M., Pritchard-Peschek, K. R., Leveritt, M. D., & Aldred, M. J. (2008). Influence of closed skill and open skill warm-ups on the performance of speed, change of direction speed, vertical jump, and reactive agility in team sport athletes. *Journal of Strength and Conditioning Research*, 22(5), 1413-1415. doi: 10.1519/JSC.0b013e3181739ecd
- Glaister, B. C., Orendurff, M. S., Schoen, J. A., Bernatz, G. C., & Klute, G. K. (2008). Ground reaction forces and impulses during a transient turning maneuver. *Journal of Biomechanics*, 41(14), 3090-3093. doi: 10.1016/j.jbiomech.2008.07.022
- Gonzalez, A. M., Hoffman, J. R., Rogowski, J. P., Burgos, W., Manalo, E., Weise, K., . . . Stout, J. R. (2013). Performance changes in NBA basketball players vary in starters vs. nonstarters over a competitive season. *Journal of Strength and Conditioning Research*, 27(3), 611-615. doi: 10.1519/JSC.0b013e31825dd2d9
- Gonzalez, A. M., Hoffman, J. R., Scallin-Perez, J. R., Stout, J. R., & Fragala, M. S. (2012). Performance changes in National Collegiate Athletic Association Division I women basketball players during a competitive season: starters vs. nonstarters. *Journal of Strength and Conditioning Research*, 26(12), 3197-3203. doi: 10.1519/JSC.0b013e318273665d
- Green, B. S., Blake, C., & Caulfield, B. M. (2011a). A comparison of cutting technique performance in rugby union players. *Journal of Strength and Conditioning Research*, 25(10), 2668-2680. doi: 10.1519/JSC.0b013e318207ed2a

- Green, B. S., Blake, C., & Caulfield, B. M. (2011b). A valid field test protocol of linear speed and agility in rugby union. *Journal of Strength and Conditioning Research*, 25(5), 1256-1262. doi: 10.1519/JSC.0b013e3181d8598b
- Haff, G. G., & Nimphius, S. (2012). Training principles for power. *Strength and Conditioning Journal*, 34(6), 2-12. doi: 10.1519/Ssc.0b013e31826db467
- Harris, G. R., Stone, M. H., O'Bryant, H. S., Proulx, C. M., & Johnson, R. L. (2000). Short-term performance effects of high power, high force, or combined weight-training methods. *Journal of Strength and Conditioning Research*, 14(1), 14-20.
- Hart, N. H., Nimphius, S., Spiteri, T., & Newton, R. (2014). Leg strength and lean mass symmetry influences kicking performance in Australian Football. *Journal of Sports Science and Medicine*, 13(1), 157-165.
- Henry, G., Dawson, B., Lay, B., & Young, W. (2011). Validity of a reactive agility test for Australian football. *International Journal of Sports Physiology and Performance*, 6(4), 534-545.
- Henry, G. J., Dawson, B., Lay, B. S., & Young, W. B. (2013). Relationships between reactive agility movement time and unilateral vertical, horizontal and lateral jumps. *Journal of Strength and Conditioning Research*(ahead-of-print).
- Hewit, J. K., Cronin, J., Button, C., & Hume, P. A. (2010). Understanding change of direction performance via the 90°turn and sprint test. *Strength and Conditioning Journal* 32(6).
- Hewit, J. K., Cronin, J. B., Button, C., & Hume, P. A. (2011). Understanding deceleration in sport. *Strength and Conditioning Journal*, 33(1), 47-52.
- Hewit, J. K., Cronin, J. B., & Hume, P. A. (2012a). Asymmetry in multi-directional jumping tasks. *Physical Therapy in Sports*, 13(4), 238-242. doi: 10.1016/j.ptsp.2011.12.003

- Hewit, J. K., Cronin, J. B., & Hume, P. A. (2012b). Multidirectional leg asymmetry assessment in sport. *Strength & Conditioning Journal*, 34(1), 82-86.
- Hewit, J. K., Cronin, J. B., & Hume, P. A. (2012c). Understanding change of direction performance: A technical analysis of a 180° aerial catch and turn task. *International Journal of Sports Science and Coaching*, 7(3), 503-514.
- Hoff, J. (2005). Training and testing physical capacities for elite soccer players. *Journal of Sports Sciences*, 23(6), 573-582. doi: 10.1080/02640410400021252
- Hoff, J., & Helgerud, J. (2004). Endurance and strength training for soccer players: physiological considerations. *Sports Medicine*, 34(3), 165-180.
- Hoffman, J. R., Ratamess, N. A., Klatt, M., Faigenbaum, A. D., & kang, J. (2007). Do bilateral power deficits influence direction-specific movement patterns? *Research in Sport Medicine* 15(2), 125-132.
- Hoffman, J. R., Tenenbaum, G., Maresh, C. M., & Kraemer, W. J. (1996). Relationship between athletic performance tests and playing time in elite college basketball players. *The Journal of Strength & Conditioning Research*, 10(2), 67-71.
- Hori, N., Newton, R. U., Andrews, W. A., Kawamori, N., McGuigan, M. R., & Nosaka, K. (2008). Does performance of hang power clean differentiate performance of jumping, sprinting, and changing of direction? . *Journal of Strength and Conditioning Research*, 22(2), 412-418.
- Hunter, J. P., Marshall, R. N., & McNair, P. (2005). Relationships between ground reaction force impulse and kinematics of sprint-running acceleration. *Journal of Applied Biomechanics*, 21(1), 31-43.
- Impellizzeri, F. M., Rampinini, E., Maffiuletti, N., & Marcora, S. M. (2007). A vertical jump force test for assessing bilateral strength asymmetry in athletes. *Medicine and Science in Sports and Exercise*, 39(11), 2044-2050. doi: 10.1249/mss.0b013e31814fb55c

- Jaric, S. (2002). Muscle strength testing: use of normalisation for body size. *Sports Medicine*, 32(10), 615-631.
- Jones, P., Bampouras, T. M., & Marrin, K. (2009). An investigation into the physical determinants of change of direction speed. *Journal of Sports Medicine and Physical Fitness*, 49(1), 97-104.
- Jullien, H., Bisch, C., Largouet, N., Manouvrier, C., Carling, C. J., & Amiard, V. (2008). Does a short period of lower limb strength training improve performance in field-based tests of running and agility in young professional soccer players? *The Journal of Strength & Conditioning Research*, 22(2), 404-411.
- Kawamori, N., Nosaka, K., & Newton, R. U. (2013). Relationships between ground reaction impulse and sprint acceleration performance in team sport athletes. *Journal of Strength and Conditioning Research*, 27(3), 568-573. doi: Doi 10.1519/Jsc.0b013e318257805a
- Keiner, M., Sander, A., Wirth, K., & Schmidtbleicher, D. (2013). Long term strength training effects on change-of-direction sprint performance. *Journal of Strength and Conditioning Research*(ahead-of-print). doi: 10.1519/JSC.0b013e318295644b
- Keiner, M., Sander, A., Wirth, K., & Schmidtbleicher, D. (2014). Long-term strength training effects on change-of-direction sprint performance. *Journal of Strength and Conditioning Research*, 28(1), 223-231. doi: 10.1519/JSC.0b013e318295644b
- Kraska, J. M., Ramsey, M. W., Haff, G. G., Fethke, N., Sands, W. A., Stone, M. E., & Stone, M. H. (2009). Relationship between strength characteristics and unweighted and weighted vertical jump height. *International Journal of Sports Physiology and Performance*, 4(4), 461-473.
- Kunz, M. (2007). Big count: 265 million playing football. *Fifa Magazine*, 10-15.

- Little, T., & Williams, A. G. (2005). Specificity of acceleration, maximum speed, and agility in professional soccer players. *Journal of Strength and Conditioning Research*, 19(1), 76-78. doi: 10.1519/14253.1
- Lloyd, R. S., Read, P., Oliver, J. L., Meyers, R. W., Nimphius, S., & Jeffreys, I. (2013). Considerations for the development of agility during childhood and adolescence. *Strength & Conditioning Journal*, 35(3), 2-11.
- Lockie, R. G., Jeffriess, M. D., McGann, T. S., Callaghan, S. J., & Schultz, A. B. (2013). Planned and reactive agility performance in semi-professional and amateur basketball players. *International Journal of Sports Physiology and Performance*(ahead-of-print).
- Lockie, R. G., Murphy, A. J., Knight, T. J., & Janse de Jonge, X. A. (2011). Factors that differentiate acceleration ability in field sport athletes. *Journal of Strength and Conditioning Research*, 25(10), 2704-2714. doi: 10.1519/JSC.0b013e31820d9f17
- Markovic, G. (2007). Poor relationship between strength and power qualities and agility performance. *Journal of Sports Medicine and Physical Fitness*, 47(3), 276-283.
- Marshall, B. M., Franklyn-Miller, A. D., King, E. A., Moran, K. A., Strike, S. C., & Falvey, E. C. (2014). Biomechanical factors associated with time to complete a change of direction cutting maneuver. *Journal of Strength and Conditioning Research, Publish Ahead of Print*. doi: 10.1519/JSC.00000000000000463
- McBride, J. M., Blow, D., Kirby, T. J., Haines, T. L., Dayne, A. M., & Triplett, N. T. (2009). Relationship between maximal squat strength and five, ten, and forty yard sprint times. *Journal of Strength and Conditioning Research*, 23(6), 1633-1636. doi: Doi 10.1519/Jsc.0b013e3181b2b8aa
- McBride, J. M., Triplett-McBride, T., Davie, A., & Newton, R. U. (2002). The effect of heavy- vs. light-load jump squats on the development of strength, power, and speed.

Journal of Strength and Conditioning Research, 16(1), 75-82. doi: 10.1519/1533-4287

McLean, S. G., Lipfert, S. W., & van den Bogert, A. J. (2004). Effect of gender and defensive opponent on the biomechanics of sidestep cutting. *Medicine and Science in Sports and Exercise*, 36(6), 1008-1016.

Meylan, C., McMaster, T., Cronin, J., Mohammad, N. I., Rogers, C., & Deklerk, M. (2009). Single-leg lateral, horizontal, and vertical jump assessment: reliability, interrelationships, and ability to predict sprint and change-of-direction performance. *Journal of Strength and Conditioning Research*, 23(4), 1140-1147. doi: 10.1519/JSC.0b013e318190f9c2

Miller, M. G., Herniman, J. J., Ricard, M. D., Cheatham, C. C., & Michael, T. J. (2006). The effects of a 6-week plyometric training program on agility. *Journal of Sports Science and Medicine*, 5(3), 459-465.

Moore, C. A., & Fry, A. C. (2007). Nonfunctional overreaching during off-season training for skill position players in collegiate American football. *Journal of Strength and Conditioning Research*, 21(3), 793-800. doi: 10.1519/R-20906.1

Newton, R. U., Gerber, A., Nimphius, S., Shim, J. K., Doan, B. K., Robertson, M., . . . Kraemer, W. J. (2006). Determination of functional strength imbalance of the lower extremities. *Journal of Strength and Conditioning Research*, 20(4), 971-977. doi: 10.1519/R-5050501x.1

Nimphius, S., McGuigan, M. R., & Newton, R. U. (2010). Relationship between strength, power, speed, and change of direction performance of female softball players. *Journal of Strength and Conditioning Research*, 24(4), 885-895. doi: 10.1519/Jsc.0b013e3181d4d41d

- Nimphius, S., McGuigan, M. R., & Newton, R. U. (2012). Changes in muscle architecture and performance during a competitive season in female softball players. *Journal of Strength and Conditioning Research*, 26(10), 2655-2666. doi: 10.1519/JSC.0b013e318269f81e
- Nuzzo, J. L., McBride, J. M., Cormie, P., & McCaulley, G. O. (2008). Relationship between Countermovement Jump Performance and Multijoint Isometric and Dynamic Tests of Strength. *Journal of Strength and Conditioning Research*, 22(3), 699-707. doi: 10.1519/Jsc.0b013e31816d5eda
- Oliver, J. L., & Meyers, R. W. (2009). Reliability and generality of measures of acceleration, planned agility, and reactive agility. *International Journal of Sports Physiology and Performance*, 4(3), 345-354.
- Peterson, M. D., Alvar, B. A., & Rhea, M. R. (2006). The contribution of maximal force production to explosive movement among young collegiate athletes. *Journal of Strength and Conditioning Research*, 20(4), 867-873.
- Portney, L., & Watkins, M. (2000). *Foundations of clinical research: Applications to practice*. Upper Saddle River, NJ: Prentice Hall.
- Reilly, T., Bangsbo, J., & Franks, A. (2000). Anthropometric and physiological predispositions for elite soccer. *Journal of Sports Sciences*, 18(9), 669-683. doi: 10.1080/02640410050120050
- Reilly, T., Williams, A. M., Nevill, A., & Franks, A. (2000). A multidisciplinary approach to talent identification in soccer. *Journal of Sports Sciences*, 18(9), 695-702. doi: 10.1080/02640410050120078
- Salaj, S., & Markovic, G. (2011). Specificity of jumping, sprinting, and quick change-of-direction motor abilities. *Journal of Strength and Conditioning Research*, 25(5), 1249-1255. doi: 10.1519/JSC.0b013e3181da77df

- Sasaki, S., Nagano, Y., Kaneko, S., Sakurai, T., & Fukubayashi, T. (2011). The relationship between performance and trunk movement during change of direction. *Journal of Sports Science and Medicine*, 10, 112-118.
- Sato, K., & Heise, G. D. (2012). Influence of weight distribution asymmetry on the biomechanics of a barbell back squat. *Journal of Strength and Conditioning Research*, 26(2), 342-349. doi: 10.1519/JSC.0b013e318220e0a3
- Sayers, S. P., Harackiewicz, D. V., Harman, E. A., Frykman, P. N., & Rosenstein, M. T. (1999). Cross-validation of three jump power equations. *Medicine and Science in Sports and Exercise*, 31(4), 572-577.
- Scanlan, A., Humphries, B., Tucker, P. S., & Dalbo, V. (2013). The influence of physical and cognitive factors on reactive agility performance in men basketball players. *Journal of Sports Sciences*(ahead-of-print), 1-8. doi: 10.1080/02640414.2013.825730
- Schmidtbleicher, D. (1992). Training for power events. . In P. V. Komi (Ed.), *Strength and power in sport* (pp. 381-395). London: Blackwell Scientific Publication.
- Serpell, B. G., Young, W. B., & Ford, M. (2011). Are the perceptual and decision-making components of agility trainable?A preliminary investigation. *Journal of Strength and Conditioning Research*, 25(5), 1240-1248.
- Sheppard, J. M., & Young, W. B. (2006). Agility literature review: classifications, training and testing. *Journal of Sports Sciences*, 24(9), 919-932. doi: 10.1080/02640410500457109
- Sheppard, J. M., Young, W. B., Doyle, T. L., Sheppard, T. A., & Newton, R. U. (2006). An evaluation of a new test of reactive agility and its relationship to sprint speed and change of direction speed. *Journal of Science and Medicine in Sport*, 9(4), 342-349. doi: 10.1016/j.jsams.2006.05.019

- Sleivert, G., & Taingahue, M. (2004). The relationship between maximal jump-squat power and sprint acceleration in athletes. *European Journal of Applied Physiology*, 91(1), 46-52. doi: Doi 10.1007/S00421-003-0941-0
- Spencer, M., Bishop, D., Dawson, B., & Goodman, C. (2005). Physiological and metabolic responses of repeated-sprint activities: specific to field-based team sports. *Sports Medicine*, 35(12), 1025-1044.
- Spencer, M., Pyne, D., Santisteban, J., & Mujika, I. (2011). Fitness determinants of repeated-sprint ability in highly trained youth football players. *International Journal of Sports Physiology and Performance*, 6(4), 497-508.
- Spiteri, T., Cochrane, J. L., Hart, N. H., Haff, G. G., & Nimphius, S. (2013). Effect of strength on plant foot kinetics and kinematics during a change of direction task. *European Journal of Sport Science*, 13(6), 646-652.
- Spiteri, T., Nimphius, S., & Cochrane, J. L. (2012). Comparison of running times during reactive offensive and defensive agility protocols *Journal of Australian Strength and Conditioning*, 20(S1), 73-78.
- Stojanovic, M. D., Ostojic, S. M., Calleja-Gonzalez, J., Milosevic, Z., & Mikic, M. (2012). Correlation between explosive strength, aerobic power and repeated sprint ability in elite basketball players. *Journal of Sports Medicine and Physical Fitness*, 52(4), 375-381.
- Stølen, T., Chamari, K., Castagna, C., & Wisløff, U. (2005). Physiology of soccer: An update. *Sports Medicine*, 35(6), 501-536.
- Stone, M. H., Moir, G., Glaister, M., & Sanders, R. (2002). How much strength is necessary? *Physical Therapy in Sport*, 3(2), 88-96.

Stone, M. H., Sanborn, K., O Bryant, H. S., Hartman, M., Stone, M. E., Proulx, C., . . .

Hruby, J. (2003). Maximum strength-power-performance relationships in collegiate throwers. *Journal of Strength and Conditioning Research*, 17(4), 739-745.

Stone, M. H., Sands, W. A., Carlock, J., Callan, S., Dickie, D., Daigle, K., . . . Hartman, M.

(2004). The importance of isometric maximum strength and peak rate-of-force development in sprint cycling. *Journal of Strength and Conditioning Research*, 18(4), 878-884. doi: 10.1519/14874.1

Stone, M. H., Sands, W. A., Pierce, K. C., Carlock, J., Cardinale, M., & Newton, R. U.

(2005). Relationship of maximum strength to weightlifting performance. *Medicine and Science in Sports and Exercise*, 37(6), 1037-1043.

Stone, M. H., Stone, M., & Sands, W. A. (2007). *Principles and practice of resistance training*. Champaign, IL: Human Kinetics

Stone, M. H., Stone, M. E., Sands, W. A., Pierce, K. C., Newton, R. U., Haff, G. G., &

Carlock, J. (2006). Maximum strength and strength training---a relationship to endurance? *Strength & Conditioning Journal*, 28(3), 44-53.

Tricoli, V., Lamas, L., Carnevale, R., & Ugrinowitsch, C. (2005). Short-term effects on lower-body functional power development: weightlifting vs. vertical jump training programs. *Journal of Strength and Conditioning Research*, 19(2), 433-437. doi: 10.1519/R-14083.1

Vescovi, J. D., & McGuigan, M. R. (2008). Relationships between sprinting, agility, and jump ability in female athletes. *Journal of Sports Sciences*, 26(1), 97-107. doi: 10.1080/02640410701348644

Wisloff, U., Castagna, C., Helgerud, J., Jones, R., & Hoff, J. (2004). Strong correlation of maximal squat strength with sprint performance and vertical jump height in elite soccer players. *British Journal of Sports Medicine*, 38(3), 285-288.

- Wisløff, U., Castagna, C., Helgerud, J., Jones, R., & Hoff, J. (2004). Strong correlation of maximal squat strength with sprint performance and vertical jump height in elite soccer players. *British Journal of Sports Medicine*, 38(3), 285-288.
- Wong, D. P., Chaouachi, A., Dellal, A., & Smith, A. W. (2012). Comparison of ground reaction forces and contact times between 2 lateral plyometric exercises in professional soccer players. *International Journal of Sports Medicine*, 33(8), 647-653.
- Young, W. B., Benton, D., Duthie, G., & Pryor, J. (2001). Resistance training for short sprints and maximum-speed sprints. *Strength and Conditioning Journal*, 23(2), 7-13. doi: 10.1519/00126548-200104000-00001
- Young, W. B., & Farrow, D. (2006). A review of agility: Practical applications for strength and conditioning. *Strength and Conditioning Journal*, 28(5), 24-29. doi: Doi 10.1519/00126548-200610000-00004
- Young, W. B., & Farrow, D. (2013). The Importance of a sport-specific stimulus for training agility. *Strength and Conditioning Journal*, 35(2), 39-43. doi: 10.1519/SSC.0b013e31828b6654
- Young, W. B., James, R., & Montgomery, I. (2002). Is muscle power related to running speed with changed of direction? *Journal of Sports Medicine and Physical Fitness*, 42(3), 282-288.
- Young, W. B., McDowell, M. H., & Scarlett, B. J. (2001). Specificity of sprint and agility training methods. *Journal of Strength and Conditioning Research*, 15(3), 315-319.
- Young, W. B., & Rogers, N. (2013). Effects of small-sided game and change-of-direction training on reactive agility and change-of-direction speed. *Journal of Sports Sciences*(ahead-of-print), 1-8. doi: 10.1080/02640414.2013.823230

- Young, W. B., Russell, A., Burge, P., Clarke, A., Cormack, S., & Stewart, G. (2008). The use of sprint tests for assessment of speed qualities of elite Australian rules footballers. *International Journal of Sports Physiology and Performance*, 3(2), 199.
- Young, W. B., & Willey, B. (2010). Analysis of a reactive agility field test. *Journal of Science and Medicine in Sport*, 13(3), 376-378. doi: 10.1016/j.jsams.2009.05.006
- Ziv, G., & Lidor, R. (2010). Vertical jump in female and male volleyball players: a review of observational and experimental studies. *Scandinavian Journal of Medicine and Science in Sports*, 20(4), 556-567. doi: 10.1111/j.1600-0838.2009.01083.x

APPENDICES

APPENDIX A: ETSU Institutional Review Board Approval



East Tennessee State University
Office for the Protection of Human Research Subjects • Box 70565 • Johnson City, Tennessee 37614-1707
Phone: (423) 439-6053 Fax: (423) 439-6060

IRB APPROVAL – Initial Expedited Review

February 11, 2014

Chieh-Ying Chiang

Re: Leg strength and power characteristics influencing change of direction and straight sprint performance in Division I soccer players

IRB#: c0114.22s

ORSPA #:

The following items were reviewed and approved by an expedited process:

- xform new protocol submission, CV of PI, informed consent document version 1/28/14*

The item(s) with an asterisk(*) above noted changes requested by the expedited reviewers.

On **February 10, 2014**, a final approval was granted for a period not to exceed 12 months and will expire on **February 9, 2015**. The expedited approval of the study *and* requested changes will be reported to the convened board on the next agenda.

The following **enclosed stamped, approved Informed Consent Documents** have been stamped with the approval and expiration date and these documents must be copied and provided to each participant prior to participant enrollment:

- Informed Consent Document (consent version 2/10/2014 stamped approved 2/10/2014)

Federal regulations require that the original copy of the participant's consent be maintained in the principal investigator's files and that a copy is given to the subject at the time of consent.

Projects involving Mountain States Health Alliance must also be approved by MSHA following IRB approval prior to initiating the study.

Unanticipated Problems Involving Risks to Subjects or Others must be reported to the IRB (and VA R&D if applicable) within 10 working days.



Accredited Since December 2005

Proposed changes in approved research cannot be initiated without IRB review and approval. The only exception to this rule is that a change can be made prior to IRB approval when necessary to eliminate apparent immediate hazards to the research subjects [21 CFR 56.108 (a)(4)]. In such a case, the IRB must be promptly informed of the change following its implementation (within 10 working days) on Form 109 (www.etsu.edu/irb). The IRB will review the change to determine that it is consistent with ensuring the subject's continued welfare.

Sincerely,
Stacey Williams, Ph.D., Vice-Chair
ETSU Campus IRB

cc: Michael Ramsey, Ph.D.

APPENDIX B: Informed Consent Document

PRINCIPAL INVESTIGATOR: Chieh-Ying Chiang

TITLE OF PROJECT: Leg strength and power characteristics influencing change of direction and sprint performance in Division I soccer players

INTRODUCTION

This informed consent will provide an explanation of the procedures associated with participating in a research project. It is very important that you read the material below and then decide if you wish to participate in the study.

PURPOSE

The purpose of this study is to investigate the influence of leg strength characteristics on change of direction (COD) ability and straight sprint abilities in NCAA Division I soccer athletes. This study is retrospective in nature and is seeking to use archived data from the ETSU athletes' monitoring program.

PROCEDURES

If you agree to be in this research, you will be asked to complete the following requirement:

Allow the researcher to analyze your data that was previously collected for non-research purposes as part of athlete monitoring program during the Spring 2013 semester. Also, this retrospective study will include analysis of following data from your athletic monitoring during Spring 2013: Body composition, height, weight, age, isometric leg strength via mid-thigh pull exercise, weighted and weighted vertical jumps, change of direction and 10m sprint.

This research will not include any data collection, as this is older data. Procedures specific to the current study include:

1. The informed consent will be given and explained in detail by primary investigator in a team meeting scheduled by ETSU men's and women's soccer coaches.
2. The informed consent will be received in a second team meeting scheduled by ETSU men's and women's soccer coach. The second meeting will be held at least two weeks from first meeting.
3. ETSU men's and women's soccer coaches only responsible for scheduling meetings, they will not be present during both meetings.

APPROVED
By the ETSU IRB
FEB 10 2014
By 
Chair/IRB Coordinator

DOCUMENT VERSION EXPIRES
FEB 09 2015
ETSU IRB

PRINCIPAL INVESTIGATOR: Chieh-Ying Chiang

TITLE OF PROJECT: Leg strength and power characteristics influencing change of direction and sprint performance in Division I soccer players

POSSIBLE RISKS/DISCOMFORTS

There will be no physical risks in this study. Confidentiality risk is minimized by the following precautions. All the required data will be assigned as subject's number to all participants and not use their name in our computer records. Only the principle and research assistant will know the name connected with a subject number. When we report the data for research publication/presentation, their names will not be used. For research purpose, data will be averaged and no individual report will be made. Data collected and analyzed for this retrospective study will be kept in the locked sport science lab office (E 113 Mini-dome) for at least 10 years after the completion of the research project. Data is only accessible by the lab coordinator, and primary and research assistant.

POSSIBLE BENEFITS

Possible direct benefits to all participants will be an analysis of your leg strength and power characteristics based on athletes' monitoring data comparing to the change of direction and sprint performance. Results can be shared with you upon request. This would benefit you on select appropriate training exercise to improve your leg strength and power, in order to maximize your change of direction and sprint abilities. Changes of direction and sprint abilities are crucial fitness for soccer athletes' regardless athletes' levels and genders. The existing literatures have not proved the underlying mechanisms of change of direction and sprint abilities related to leg strength and power characteristics in collegiate soccer population. The expected result would show a potential benefits include knowledge generated which will contribute to understand true effect of leg strength and power on soccer athletes' change of direction and sprint abilities. This research project would greatly be appreciated.

FINANCIAL COSTS

There is no financial cost to you and there is no compensation for participation in this study.

VOLUNTARY PARTICIPATION

Participation in this research project is voluntary. There are no consequences associated with refusal to participate. Furthermore, you may withdraw your information from the study at any time. Your standing on the team, scholarship, or grades from classes taught by any of the investigators will not be affected by lack of participation in this study. You can withdraw at any time by calling Chieh-Ying Chiang whose number is 423-773-1248, or Dr. Kimitake Sato whose number is 423-439-5138.

Ver. 02/10/14

APPROVED
By the ETSU IRB
FEB 10 2014
By 
Chair IRB Coordinator

Page 2 of 3

DOCUMENT VERSION EXPIRES

FEB 09 2015

ETSU IRB

Subject Initials _____

PRINCIPAL INVESTIGATOR: Chieh-Ying Chiang

TITLE OF PROJECT: Leg strength and power characteristics influencing change of direction and sprint performance in Division I soccer players

CONTACT FOR QUESTIONS

If you should have any questions, comments, concerns or research-related problems, please call Chieh-Ying Chiang at 404-775-8112 or Dr. Kimitake Sato whose number is 423-439-5138. You can reach the chairman of the Institutional Review Board at 423-439-6054 with any questions you may have about your individual rights as a subject in human research. If you have and questions or concerns and would rather talk to someone independent of the research project, you can reach the IRB coordinator at 423-439-6055 or 423-439-6002.

CONFIDENTIALITY

We will take every precaution to protect participants' privacy. We will assign a subject number to all participants and not use their names in our computer records. Only the principle and research assistant know the name connected with a subject number and when we report the data, their name will not be used for research. For research purpose, data will be averaged and no individual report will be made. The research data was recorded on University-owned laptop that is password protected. The laptop will be kept in the locked sport science lab office (E 113 Mini-dome) when not in-use, and during the duration of research project. The data will also be kept for at least 10 years after the completion of the research project. Data is only accessible by the lab coordinator, and primary and research assistant. The ETSU Institutional Review Board (IRB) also has access to the study records.

By signing below, you confirm that you have read or had this document read to you. You will be given a signed copy of this informed consent document. You have been given the chance to ask questions and to discuss your participation with the investigator. You freely and voluntarily choose to be in this research project.

SIGNATURE OF PARTICIPANT

DATE

PRINTED NAME OF PARTICIPANT

DATE

SIGNATURE OF INVESTIGATOR

DATE

SIGNATURE OF WITNESS (if applicable)

DATE

APPROVED
By the ETSU IRB

DOCUMENT VERSION EXPIRES

Ver. 02/10/14

FEB 10 2014

By
Chair/IRB Coordinator

Page 3 of 3

FEB 09 2015

ETSU IRB

Subject Initials _____

VITA

CHIEH YING CHIANG

- Education: B.S. Sports and Leisure Studies, National Dow Hwa University, Hualiaen, Taiwan 2005
M.S. Sports Science, National Taiwan Sports University, Taoyuan, Taiwan 2008
Ph.D. Sport Physiology and Performance, East Tennessee State University, Johnson City, TN 2014
- Professional Experience: Strength and Conditioning Coach, Chinese Taipei Women's Basketball Team, Taiwan, 2010
Strength and Conditioning Coach, East Tennessee State University Baseball, Johnson City, TN 2011-2014
Graduate Assistant, East Tennessee State University Baseball, Johnson City, TN 2011-2012
Doctoral Research Fellow, East Tennessee State University Baseball, Johnson City, TN 2012-2014
- Publications: Bailey, CA, Sato, K, Alexander, R, Chiang, C, Stone, MH. 2013. "Isometric force production symmetry and jumping performance in college athletes." *Journal of Trainology*, 2(1), 1-5.
- Hoffmann, J. J., Reed, J. P., Leiting, K., Chiang, C. Y., & Stone, M. H. (2014). Repeated sprints, high-intensity interval training, small-sided games: Theory and application to field sports. *International Journal of Sports Physiology and Performance*, 9(2), 352-357.
- Bazyler, C, Bailey, CA, Chiang, CY, Sato, K, Stone, MH. 2014. "The effects of strength training on isometric force production symmetry in recreational athletes." *Journal of Trainology*, 3(1), 6-10.
- Honors and Awards: Government study aboard scholarship- administration of education, Taiwan, 2011
- Hornsby, WG, Bailey, CA, Chiang, CY, Johnston, BJ, Gentles, J, and Stone, MH. "Relationship between isometric force characteristics and hitting performance in NCAA Division I baseball players." Sixth Annual Coaches and Sport Science College, Johnson City, TN 2011.) (1st Place award winner for Sport Science)