UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Strength factors associated with performance in change of direction tasks at different angles

by

Christo van Zyl

a dissertation submitted in partial fulfilment of the requirements for the

degree MSc (Sports Science)

in the Division of Biokinetics and Sport Science

Department of Physiology

Faculty of Health Sciences

University of Pretoria

Supervisor: Dr Helen Bayne

Co-supervisor: Dr Jason C Tee

Statistician: Dr Joyce Jordaan

2021

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

PLAGIARISM DECLARATION

Full Name: Christo van Zyl

Student number: 15200885

Degree: MSc Sport Science

Title of thesis: **Strength factors associated with performance in change of direction at different angles.**

I declare that this thesis/dissertation is my own original work. Where secondary material is used, this has been carefully acknowledged and referenced in accordance with university requirements.

I understand what plagiarism is and am aware of university policy and implications in this regard.

Signature: Date: 20/11/2021

ACKNOWLEDGEMENTS

I wish to extend my deepest appreciation to the following people, without whose assistance and support this dissertation would have been impossible:

Dr H. Bayne, my supervisor, Department of Physiology, University of Pretoria, for her motivation and patience in supervising this study and being a source of inspiration.

Dr JC. Tee, my co-supervisor, Director of sport, St Johns College Preparatory, for his support and patience in supervising this study and being a source of inspiration.

Ms JC. Jordaan, for her valuable advice and assistance with data analysis in this study.

Division of Biokinetics and Sport Science, Department of Physiology, University of Pretoria, for providing the platform and resources for the data collection in this study.

TuksSport and the TuksHockey club, for their generous support and volunteering the use of their facilities and equipment involved in this study.

Sport, Exercise Medicine and Lifestyle Institute (SEMLI), University of Pretoria, for their generous support and volunteering of their facilities, equipment, and expertise involved in this study.

TuksHockey men's and woman's teams, for their willingness to participate in scientific research.

Jeppe High School for Boys, rugby players and staff, for granting me the opportunity to complete this study as well as selflessly volunteering to be part of scientific research.

To my family Christo E van Zyl, Lelani van Zyl, Julian van Zyl, and Adoreé Snyman, thank you for your love, support, and willingness to be part of this process. A journey that is not possible unless you have the right people as your support structure.

TABLE OF CONTENTS

List of symbols and abbreviations

1RM	1-repetition maximum
3RM	3-repetition maximum
4BT	4-bounce test
5JT	5-jump test
Bilat	Bilateral
BJ	Broad jump
cm	centimetre
CMJ	Countermovement jump
COD	Change of direction
CODD	Change of direction deficit
$CODD_{45}$	45-degree cutting task change of direction deficit
$CODD_{90}$	90-degree cutting task change of direction deficit
$CODD_{180}$	180-degree cutting task change of direction deficit
CODP	Change of direction performance
CV	Coefficient of variation
D	Dominant
DBT	Drive block test
DJ18	Drop jump off an 18cm box
DJ20	Drop jump off a 20cm box
DJ30	Drop jump off a 30cm box
DJopt	Drop jump off an optimal height box
e.g.	for example
EOT	Eccentric overload training
ES	Effect size
E-S	Endurance strength
F_{CMJ}	Countermovement jump peak force
F/BM_{CMJ}	Countermovement jump relative peak force

F/BM_{ISQ}	Isometric squat relative peak force
F/BM_{RJT}	Repeated jump test relative peak force
H_{CMJ}	Countermovement jump – jump height
H_{RJT}	Repeated jump test jump height
HIIT	High-intensity interval training
i.e.	in other words
IMTP	Isometric mid-thigh pull
IsoSqt	Isometric squat
JS	Jump squat
kg	kilogram
L	Left
LJ	Lateral jump
m	metre
M_{CMJ}	Countermovement jump take-off momentum
min	minute
MPP	Mean propulsive power
ms	milliseconds
ND	Non-dominant
N/kg	Newton per kilogram
Ns	Newton seconds
P/BM	Power relative to body mass
PBT	Percentage-based training
PE	Parameter of estimate
PF	Peak force
PHV	Peak height velocity
PP	Peak power
R	Right
RJ	Repeated jump

RJT	Repeated jump test
RLBT	Repeated lateral bound test
RSI	Reactive strength index
RSI_{CMJ}	Countermovement jump reactive strength index
RSI_{RJT}	Repeated jump test reactive strength index
s	second
S-E	Strength endurance
S&E	Strength and endurance
SJ	Squat jump
T_{45}	45-degree cutting task time to completion
T_{90}	90-degree cutting task time to completion
T_{180}	180-degree cutting task time to completion
TJ	Triple jump
Unilat	Unilateral
VBT	Velocity based training
Z-Z	Zig-zag change of direction test

List of figures

List of tables

Abstract

Title: Strength factors associated with performance in change of direction tasks at different angles.

Change of direction (COD) ability is a determinant of field and court sports performance and can be quantified using two different methods. Change of direction performance (CODP) is the time taken to complete the whole task of sprinting into a turn, changing direction, and sprinting out of the turn. Change of direction deficit (CODD) is used to isolate COD skill from linear acceleration and deceleration capabilities and is simply the time taken to complete a COD task minus the time to complete a linear sprint of the same distance. Different COD tasks place different demands on the body. During a 180-degree cutting task, the athlete momentarily comes to a complete stop which means that higher levels of force production are required to overcome inertia during the deceleration and reacceleration phases of the COD task. A 45-degree cutting task allows the athlete to maintain running momentum through the COD task and thus requires a smaller change of momentum as they change direction. The demands of a cutting task at 90-degrees fall between the 180-, and 45-degree cutting tasks. Because the physical demands of these tasks are fundamentally different, it follows that different strength qualities may determine performance in COD at different angles. Strength qualities at different points on the force-velocity curve might be related to different task demands. The relationship between isometric, ballistic, plyometric strength and CODP in different COD tasks is yet to be clearly defined. Thus, the study aimed to determine the relationship between different strength factors and performance during COD tasks at different angles. This information can inform training program design to optimise movement capacities for different sports.

Twenty male high school rugby players (age = 16.8 ± 1.1 years), twelve male university-level hockey players (age = 20.5 ± 1.7 years), and thirteen university-level female hockey players (age = 20.6 ± 1.5 years) volunteered to be part of this study. Maximal isometric strength was assessed with the isometric squat test. The ballistic strength capabilities of the athletes were evaluated with a countermovement jump. The 10-to-5 repeated jump test was used to evaluate the plyometric strength capabilities of the athletes. The athletes performed a 20-m linear sprint to calculate CODD during the COD tasks. Change of direction ability was assessed using single directional changes at 180-, 90-, and 45-degrees. Pearson's correlation was used to assess the relationship between the different tests. Stepwise multiple regression analyses were done to determine the best predictor variables during the different COD tasks.

There were significant correlations between isometric squat performance and CODP at all angles, but it was only a significant predictor variable for CODD during a 45-degree cutting task. Countermovement jump height showed the strongest relationship among the countermovement jump variables with CODP. Take-off momentum, however, was the countermovement jump performance variable that best predicted performance and only in the 90-degree cutting task. Plyometric strength, as measured by the jump height and peak force relative to body mass during the repeated jump test, had significant correlations with CODP at all angles, and was the best predictor variable during the 180- and 45-degree cutting tasks.

It would be of interest to practitioners to improve the athlete's ability to generate high levels of force as isometric strength underpins ballistic and plyometric performance, but it seems that the ability to produce force as quickly as possible as demonstrated in jump tasks rather than the maximum amount of force that can be produced is a better predictor of performance. Strength and conditioning coaches who want to improve CODP at different angles of directional change need to improve their athletes' ability to produce high levels of force first and then with the use of plyometric movements increase the ability to produce force as quickly as possible.

Key words: change of direction performance, change of direction deficit, lower body strength, plyometric.

Chapter 1

Scope and Intent

1 Introduction

Agility is an athletic attribute that is composed of a cognitive decision in reaction to an environmental stimulus followed by the execution of a whole-body movement pattern to change direction.[1] The ability to change direction effectively is underpinned by accelerative and decelerative capacities and effective movement patterns during the turn itself.

Change of direction (COD) ability has been related to decisive moments in a team sport that could impact the outcome of a match. Change of direction is a component of agility that is described as the ability to decelerate, change movement direction, and accelerate again where no immediate reaction to a stimulus is required, thus the direction change is pre-planned.[1-4] Some of the tests typically used by sport scientists and/or strength and conditioning coaches to assess COD performance include but are not limited to the 505 COD test, Pro-agility test, Illinois agility test, T-test, and the 45- and 90-degree cutting test. These tests consist of different combinations of running distances, number of directional changes, and angle of cuts. The choice of agility test by the practitioner is highly dependent on the sporting code of the athletes. Some sports, such as cricket and netball, involve more 180-degree turns and would thus justify the use of a COD performance test that evaluates their ability to decelerate, momentarily stop while changing direction, and re-accelerate in the opposite direction (i.e., the 505 COD test). Other sports, such as football and rugby require mostly changes in direction that are 90-degrees and smaller where they decelerate, perform a cutting manoeuvre, and re-accelerate in the new direction. A test to assess the COD performance using a single-cut manoeuvre of 90-degrees or less, therefore, might be more useful for these sports.[5] Change of direction deficit (CODD) is a calculation used to isolate the ability to change direction from the ability to sprint in a straight line. This has been suggested to provide a more isolated measure of COD ability which is not influenced by linear speed qualities.[6-9]

While it has been useful to isolate COD ability from sprint ability, the physical performance capabilities that underpin CODP are yet to be clearly defined. Change of direction performance is suggested to be influenced by technique, straight line running speed, and lower limb strength and power qualities.[4] More particularly, 180-, 90-, and 45-degree cut tasks are fundamentally different, and therefore may be underpinned by different performance capabilities. When changing direction, athletes must rapidly and systematically coordinate force and impulse application during the braking-, plant-, and propulsive phase of the movement.[4,10] During a 180-degree turn, the athlete momentarily comes to a complete stop before pushing off in the direction they came from. This means that for a brief period of time the athlete has a velocity of zero.[11] High levels of force production are thus required by the athlete to overcome inertia and accelerate.[11-12] During a 45-degree turn, the athlete maintains enough momentum throughout the turn to allow for lower force production requirements to redirect their motion.[13] The 90-degree cutting task is thus placed between the 180- and 45-degree cutting task in terms of momentum maintained and the reacceleration demands. Knowledge of the different physical capacities that underpin performance in the various types of COD manoeuvres will support strength and conditioning coaches in designing training programs to improve performance in COD tasks.

Strength is defined as the ability to produce force against an external resistance.[14] The force output and contraction velocity of human muscles are inversely related, and individual muscles groups have revealed an approximately hyperbolic force-velocity relationship.[15] In figure 1 this hyperbolic relationship between force and velocity is presented. The point on the graph where concentric muscle contraction force is maximal corresponds to a velocity equal to zero, also known as an isometric movement. Isometric strength represents the maximum possible amount of force that an athlete is capable of producing during a concentric muscle contraction, but this occurs without any constraints placed on the time to produce force. The isometric squat or isometric mid-thigh pull can be used to assess peak force which is deemed very reliable and can be used to assess maximum lower body strength capabilities.[14] When available, these tests are preferred in practice over dynamic tests such as the 1-repetition max test for their reduced injury risk, relatively simple administration and high test-retest reliability.[14] Ballistic movements, such as jumping or throwing, requires the athlete to exert as much force as possible in short periods of time, with the goal of projecting the accelerated object into free space.[16] Plyometric movements, such as hopping or skipping, emphasize the loading of muscles during an eccentric muscle action, which is quickly followed by a rebound concentric action.[17] While it is true that ballistic strength requires maximal force development in a short period of time[16], the same is also true for plyometric movements. Although both ballistic and plyometric movements fall on the opposite end of the force-velocity curve in relation to isometric movements, ballistic movements usually have a higher force production compared to plyometric movements. Additionally, plyometric movements have shorter contraction times compared to ballistic movements.

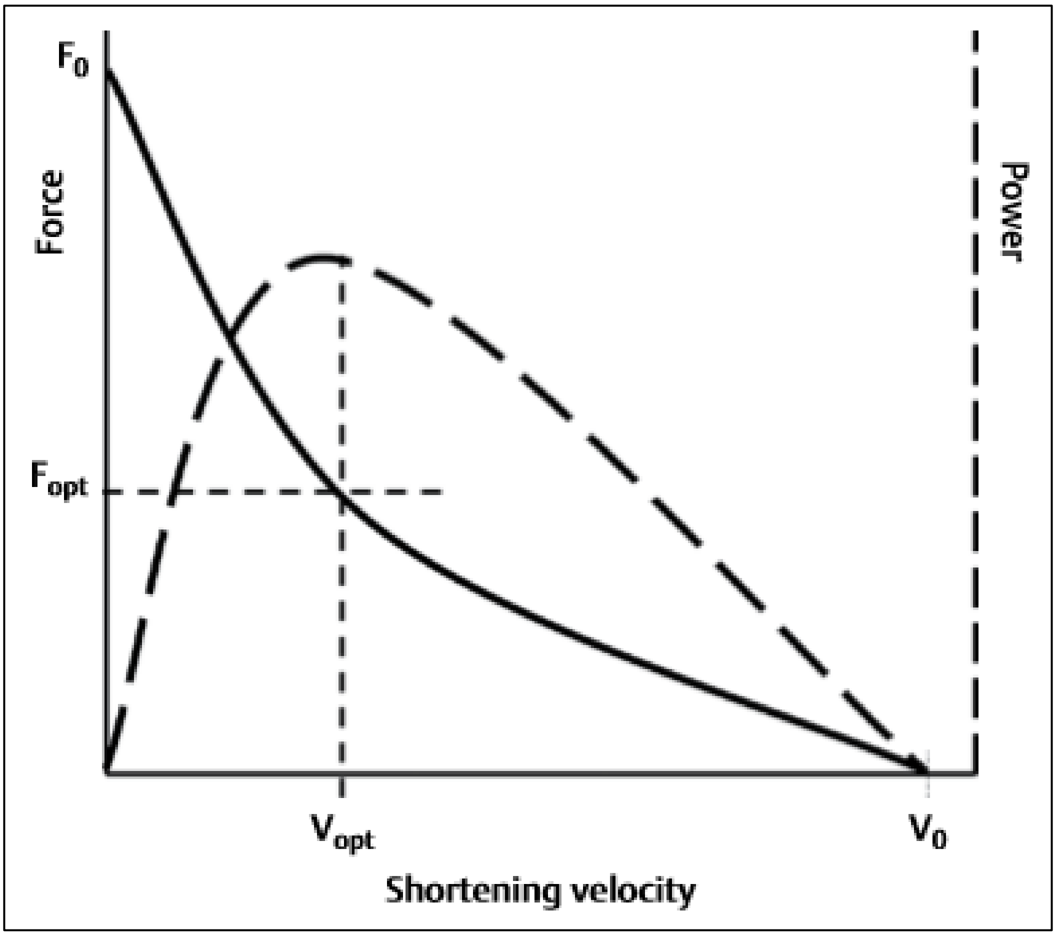

Figure 1: Force-velocity curve as presented by the solid line and power-velocity curve as presented by the dashed line.[15]

There is, however, little empirical evidence available as to which component of strength is best related to COD ability calculated as either CODP or CODD. To produce a fast COD, it would be desirable to achieve adequate momentum change through the directional change phase to overcome inertia and accelerate the centre of mass in the new direction. To our knowledge, there is a lack of literature that examines the relationship between these lower limb strength qualities across the range of different types of cutting tasks.

2. Research problem

There are many instances in team field and court sports where the movement demands are characterized more by rapid COD rather than running in a straight line.[18] This leads to the question, is it better to train isometric-, ballistic-, or plyometric strength capacities when aiming to positively influence the ability to change direction? Would there be a difference between the lower body strength components during a 180-, 90-, and 45-degree turn? Knowledge of this could help practitioners better target specific goals when training athletes participating in sports where changing direction is important for performance in their sport. Strength and conditioning coaches could find it useful to understand the relationship between CODP and isometric-, ballistic-, and plyometric strength to better be able to train the specific strength qualities required during a change of direction task.

3. Aim and objectives

This study aimed to investigate the relationship between COD ability quantified using both CODP and CODD measures in 180-, 90-, and 45-degree cutting tasks and lower body isometric, ballistic and plyometric strength in team sport athletes.

Objectives:

1) Determine the relationship between CODP and CODD in a 45-degree cutting task and lower body isometric, ballistic, and plyometric strength.
2) Determine the relationship between CODP and CODD in a 90-degree cutting task and lower body isometric, ballistic, and plyometric strength.
3) Determine the relationship between CODP and CODD in a 180-degree cutting task and lower body isometric, ballistic- and plyometric strength.

These objectives were addressed through a correlational analysis to investigate associations between parameters, and linear regression analysis to investigate which of the parameters best predict performance in these tasks.

4. Outline of the dissertation

The remainder of the dissertation consists of:

- Chapter 2: A literature review relating to the relationship between lower body isometric, ballistic, and plyometric strength and change of direction performance using various COD tasks.
- Chapter 3: A detailed experimental study in draft manuscript format.
- Chapter 4: A discussion of the research results along with the limitations of the study and the recommendations for future research.

Chapter 2: Literature Review

Introduction

The ability to change direction while in motion is a determinant of performance in field and court sports.[1,19] Agility has been defined as a whole-body movement with a change in velocity and/or direction in response to a stimulus.[1] Change of direction performance (CODP) forms the physical foundation for agility, as it incorporates the mechanics associated with agility performance i.e. deceleration, directional change, and acceleration.[7] Change of direction performance is simply put the overall task that involves a maximum effort run into a turn, directional change and a maximal effort run out of the turn, and can be assessed as the total time to complete a change of direction task.

Change of direction biomechanics is both angle- and velocity dependant, where there is a trade-off between the angle of directional change and the velocity maintained throughout the cutting task.[13] A sharper COD angle results in reduced approach and exit velocities and demands higher magnitudes of knee joint loading, thereby affecting the deceleration and reacceleration requirements of the COD task.[13] More particularly, 180-, 90-, and 45-degree cutting tasks are fundamentally different in the amount of velocity that is maintained during the COD, and therefore may be underpinned by different performance capabilities. During a 180-degree turn, the athlete momentarily comes to a complete stop before pushing off in the opposite direction. This complete stop results in a velocity of zero for a short period of time which means that no momentum is maintained.[13] The athlete would then need to produce more force during the acceleration phase to overcome inertia and increase velocity, which results in longer ground contact times during the acceleration phase.[11-12] On the other end of the COD spectrum, tasks with a lower cutting angle (e.g., 45 degrees) allow some momentum to be maintained through the turn.[13] More momentum maintained from the entry velocity results in less force production needed by the athlete to accelerate the centre of mass enough to overcome inertia.[12] Force production requirements to overcome inertia by the athlete during the deceleration and reacceleration phases of a 90-degree turn would be in between the 180-degree and 45-degree COD tasks. The athlete maintains more momentum through the 90-degree directional change compared to a 180-degree cutting task, but less compared to a 45-degree cutting task. This leads to the suggestion that different angles of cutting tasks require different strength training demands.

Maintaining velocity through the cutting task is an important determinant of CODP.[13,20-21] Using completion time as a measure from an agility test, however, may mask deficiencies in CODP, particularly for athletes with good acceleration or sprinting ability.[7] Change of direction deficit (CODD) is a measure that aims to quantify the change of direction skill the athlete demonstrates and provide a more isolated measure of COD skill that is not influenced by linear speed qualities.[6-9] Nimphius and colleagues[3] first defined this concept in 2013 as the additional time that a single directional change requires when compared with a pure linear sprint over equivalent distance. They also stated that during a 505 COD task (table 1) only 33% of the total time is spent changing direction, while the remaining 66% of the time is spent accelerating and sprinting.[7]

The ability to produce force against an external resistance is known as strength.[14] Dynamic strength is the maximal amount of force an athlete is capable of producing with a change in joint angles. An athlete's ability to produce maximal force without a change in joint angles is known as isometric strength, and this occurs without any constraints placed on the time to produce force. Ballistic and plyometric strength falls on the other end of the force-velocity curve to maximal dynamic and isometric strength, with ballistic strength generally requiring higher levels of force production. Lower body ballistic strength consist of jumping movements and require the athlete to exert as much force as possible in short periods of time, with the goal of projecting the accelerated body into free space.[16] Ballistic movements can be classified as jumping events with a slow stretch-shortening cycle (contraction time > 250ms), while plyometric events can be classified as jumping events with a fast stretch-shortening cycle (contraction time < 250ms).[22] Lower body plyometric strength consists of hopping movements and emphasizes the utilization of the stretch-shortening cycle.[17]

Multiple factors influence CODP such as technique, straight line running speed, and lower limb strength and power qualities.[4] When changing direction, athletes must rapidly and systematically coordinate force and impulse application during the deceleration, directional change, and reacceleration phases of the COD task.[4,10] Strength qualities in the lower limbs have been well established to be a determinant of CODP.[18] Leg muscle qualities can be seen as the umbrella term for reactive strength, concentric strength, and power.[23] There is, however, limited research on the exact mechanism of these lower limb strength qualities that underpin CODP. The effect of training interventions on CODP can be very useful to strength and conditioning coaches in understanding the exact mechanisms that underpin CODP. Maximal dynamic strength can be trained using higher loads and lower repetition ranges. Plyometric strength is trained by utilizing the stretch-shortening cycle and is mainly achieved with jumping movements.[24]

Strength and conditioning coaches could find it useful to understand the relationship between CODP and isometric-, ballistic-, and plyometric strength to better be able to train the specific strength qualities required during a change of direction task. To my knowledge, previous research has investigated the relationship between strength and 180-degree cutting tasks but there is a lack of literature that examines the relationship between these lower limb strength qualities and 90-degree and 45-degree cutting tasks. Therefore, a review of literature is needed to critically evaluate existing relationships between 180-degree cutting tasks and lower limb strength factors as well as identify gaps in the literature examining the relationships between 90-degree and less cutting tasks and lower body strength qualities.

Methodology

Research design

The purpose of this search was to examine existing literature to summarize previously reported relationships between strength qualities and CODP. The search was guided by two research objectives: 1) to determine the relationship between lower body multi-joint muscular strength measures and CODP, and 2) to determine the effects of lower body multi-joint muscular strength training interventions on CODP.

Search strategies

To determine the relationship between lower body isometric-, ballistic-, and plyometric strength and change of direction performance using various COD tasks, PubMed and SPORTDiscus were selected as the designated online databases via EBSCOhost. Figure 2 outlines the approach used to search. The specific Boolean syntax used for the search was *"change of direction deficit" OR "change of direction ability" OR "change of direction perform*" OR "agility perform" AND "sport" AND "strength"* with no date restrictions up to end of July 2021.

Inclusion/exclusion criteria

To be eligible for inclusion, papers had to (1) address at least one of the research objectives mentioned above, (2) be original peer-reviewed research, and (3) be written in English. Papers that were only available in languages other than English, published in non-peer-reviewed journals, and/or duplicates were excluded from this review. Studies that examined the effects of training interventions and did not report their results using effect sizes were excluded from this review. This brought the final number of papers to be reviewed from this search to 68.

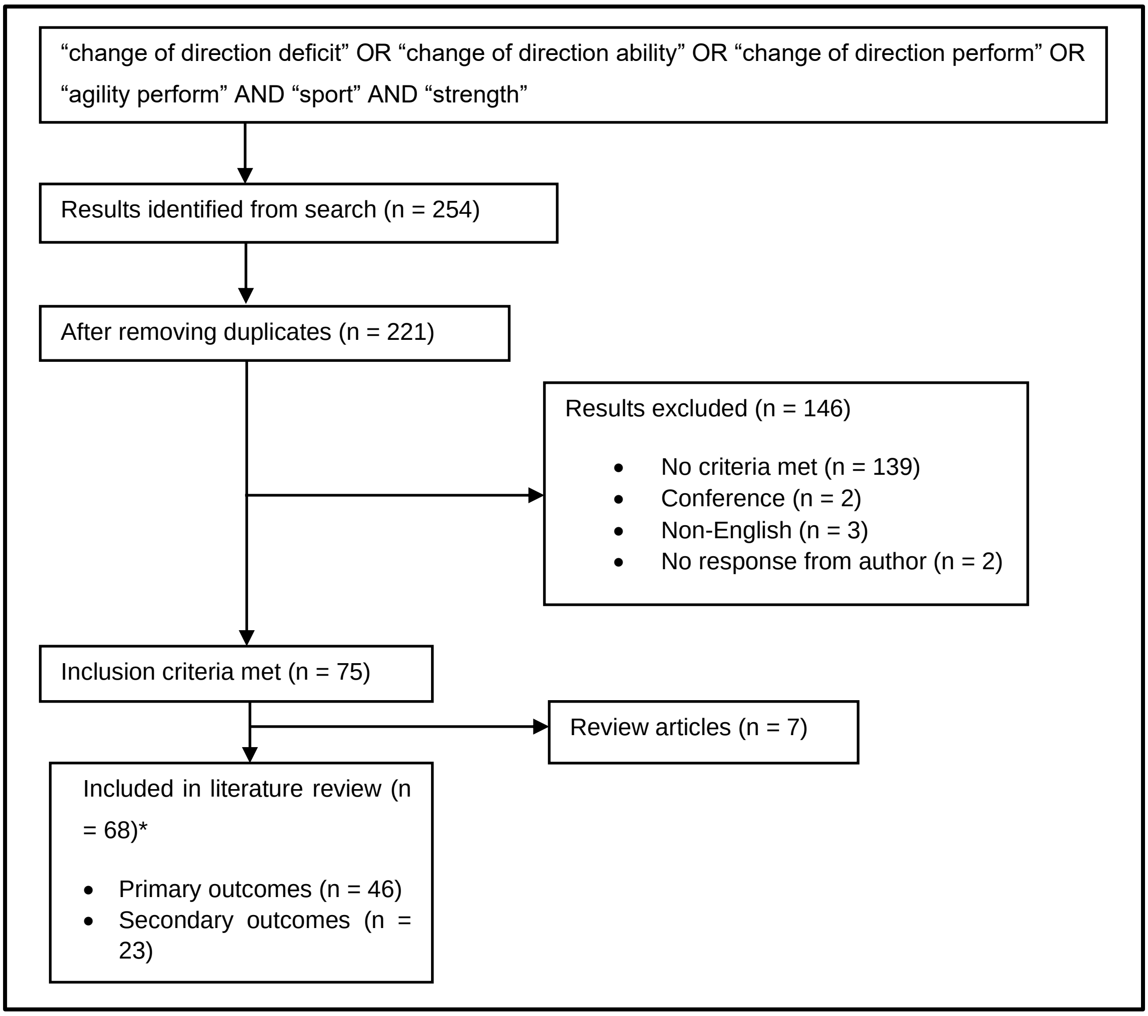

Figure 2: Approach used to sort articles returned from the search. *Nimphius et al.[25] contained both a primary and secondary outcome.

Assessment of relationships

Results from the papers were divided into two categories based on the stated objectives; 1) correlational analyses between various strength factors and change of direction performance, and 2) the effect of various strength training interventions on change of direction performance. Only results that could be filtered into one of the following divisions of relationships were extracted: CODP and maximal dynamic strength; CODP and maximal isometric strength; CODP and ballistic strength; CODP and plyometric strength. Results of correlational analyses (Tables 2-4) were classified as trivial ($r < 0.1$), small ($0.1 < r < 0.3$), moderate ($0.3 < r < 0.5$), large ($0.5 < r < 0.7$), very large ($0.7 < r < 0.9$), and nearly perfect ($r > 0.9$).[26] These results were then further pooled into meaningful relationships (moderate to nearly perfect), non-meaningful relationships (trivial to small), and mixed relationships (combination of meaningful and non-meaningful results). These cut-off values were selected as a moderate effect is likely to be practically meaningful in sports performance.[27] Significance was indicated by reporting the p-values, with statistical significance was set at $p \leq 0.05$.

Effect sizes were used to determine the magnitude of training effect (Table 5) on CODP and were classified as trivial ($d < 0.2$), small ($0.2 < d < 0.6$), moderate ($0.6 < d < 1.20$), large ($1.20 < d < 2.0$), very large ($2.0 < d < 4.0$), and extremely large ($d > 4.0$).[26] Similarly, these results were further classified into meaningful and non-meaningful effects with the cut-off for meaningful effects being moderate effect sizes. All studies that revealed a combination of meaningful and non-meaningful results were classified as mixed results. For this literature review, countermovement jumps were classified as a ballistic task as this movement is typically classified as a slow stretch-shortening cycle because it features a contraction time of >250ms.[22]

Results

A variety of COD tests (table 1) were used across the literature. A summary of the analyses of papers assessing the relationship between CODP and maximal strength, ballistic strength, and plyometric strength are presented in tables 2, 3, and 4 respectively. A summary of papers investigating the effect of training interventions on CODP is presented in table 5.

Table 1. Different agility tests used in the literature with their angles and number of directional changes as well as total distance covered.

Agility test	Angle of directional change	Number of directional changes	Total distance covered
T-test	90°, 180°, 180°, 90°	4	40-m
505 test	180°	1	20-m
Pro-agility test	180°	2	20-m
Slalom run	5 cone swerve, 180°, 5 cone swerve	11	24-m
3 x 90° cut	90°	3	20-m
3 x 135° cut	135°	3	20-m
45° cut	45°	1	10-m
90° cut	90°	1	10-m
135° cut	135°	1	10-m
Arrowhead	90°, 135°,135°	3	37-m
Illinois	180°, 180°, 2 cone swerve, 180°, 2 cone swerve, 180°	9	60-m
Zig-Zag test	100°	4	25-m
3 x 180° cut	180°	3	20-m
2 x 180° cut	180°	2	20-m
10m x 5 COD	180°	4	20-m
Double cut	90°	2	30-m

Agility test	Angle of directional change	Number of directional changes	Total distance covered
20° cut	20°	1	8-m
40° cut	40°	1	8-m
60° cut	60°	1	8-m
4 x 60° cut	60°	4	8-m
50° cut	50°	1	5-m
V-cut	45°	4	25-m
9-cone test	8 x 180°, 4 x 150°, 3 x 120°	15	74-m
Half T-test	90°, 180°, 180°, 90°	4	20-m
Modified Illinois test	180°, 180°, 2 cone swerve, 180°, 2 cone swerve, 180°	9	30-m
4 x 5m	90°, 90°, 180°	3	20-m
9-3-6-3-9 agility test	180°	9	60-m
15m agility run	3 cone swerve	2	15-m
Meylan COD test	60°	4	10-m

Table 2. Relationship between multi-joint lower body maximum dynamic and isometric strength factors and change of direction performance.

Authors	Athletes	What was compared	Strength vs COD r-value	Strength vs COD p-value	Magnitude
Bourgeois et al.[28]	17 collegiate American football players aged: 20.5 ± 1.3 years	1RM back squat vs T-test 1RM back squat vs Pro-agility test	1RM back squat vs T-test = 0.61 1RM back squat vs Pro-agility = 0.71	$p < 0.05$ $p < 0.05$	large very large
Delaney et al.[29]	31 male professional rugby league players aged 24.3 ± 4.4 years	3RM back squat vs 505	3RM back squat vs D = -0.28 3RM back squat vs ND = -0.21	$p > 0.05$ $p > 0.05$	small small
Markovic[30]	76 physical education students aged 20.7 ± 1.7 years	Isometric-squat-PF vs Slalom run Isoinertial squat vs Slalom run	Isometric-squat-PF vs Slalom run = 0.01 Isoinertial squat vs Slalom run = -0.21	$p > 0.05$ $p > 0.05$	trivial small
Nimphius et al.[31]	10 female softball players aged 18.1 ± 1.6 years	Relative 1RM back squat vs 505	Pre-season: ND = -0.75 D = -0.50 Mid-season: ND = -0.73 D = -0.75 Post-season: ND = -0.85 D = -0.60	 $p < 0.05$ $p > 0.05$ $p < 0.05$ $p < 0.05$ $p < 0.05$ $p > 0.05$	 very large large very large very large very large large

Authors	Athletes	What was compared	Strength vs COD r-value	Strength vs COD p-value	Magnitude
Nimphius et al.[25]	10 female softball players aged 18.1 ± 1.6 years	Relative 1RM back squat vs 505	D = -0.70 ND = -0.51	$p > 0.05$ $p > 0.05$	very large large
Papla et al.[32]	15 elite male soccer players aged 21.7 ± 0.72 years	1RM back squat vs 3x90° cut 1RM back squat vs 3x135° cut	1RM back squat vs 3x90 = -0.17 1RM back squat vs 3x90 CODD = -0.02 1RM back squat vs 3x135° = -0.05 1RM back squat vs 3x135° CODD = -0.01	$p > 0.05$ $p > 0.05$ $p > 0.05$ $p > 0.05$	small trivial trivial trivial
Ranisavljev et al.[33]	30 males aged 20.7 ± 1.3 years	1RM back squat vs T-test Relative 1RM back squat vs T-test	1RM back squat = -0.16 Relative 1RM back squat = -0.05	$p = 0.397$ $p = 0.791$	small trivial
Scanlan et al.[34]	24 male adolescent basketball players aged 16 to 18 years	IMTP-PF vs T-test Relative IMTP-PF vs T-test	IMTP-PF = -0.24 Relative IMTP-PF = -0.55	$p = 0.26$ $p = 0.006$	small large

Authors	Athletes	What was compared	Strength vs COD r-value	Strength vs COD p-value	Magnitude
Spiteri et al.[35]	12 female basketball players aged 24.25 ± 2.55 years	Relative 1RM back squat vs 505	Relative 1RM back squat vs 505 = -0.80	p < 0.01	very large
		Relative 1RM back squat vs T-test	Relative 1RM back squat vs T-test = -0.80	p < 0.01	very large
		Relative Concentric strength vs 505	Relative Concentric strength vs 505 = -0.79	p < 0.01	very large
		Relative Concentric strength vs T-test	Relative Concentric strength vs T-test = -0.79	p < 0.01	very large
		Relative Eccentric strength vs 505	Relative Eccentric strength vs 505 = -0.89	p < 0.01	very large
		Relative Eccentric strength vs T-test	Relative Eccentric strength vs T-test = -0.88	p < 0.01	very large
		IMTP-PF vs 505	IMTP-PF vs 505 = -0.79	p < 0.01	very large
		IMTP-PF vs T-test	IMTP-PF vs T-test = -0.85	p < 0.01	very large
Swinton et al.[36]	30 nonprofessional rugby union players aged 24.2 ± 3.9 years	Relative 1RM back squat vs 505	Relative 1RM back squat vs. 505 = -0.70	p < 0.01	very large
		Relative 1RM deadlift vs 505	Relative 1RM deadlift vs. 505 = -0.72	p < 0.01	very large
Wang et al.[37]	15 university-level rugby players aged 20.67 ± 1.23 years	IMTP-PF vs Pro-agility test	IMTP-PF vs Pro-agility = -0.11	p > 0.05	small
		IMTP-PF vs T-test	IMTP-PF vs T-test = -0.07	p > 0.05	trivial

Abbreviations: 1RM: one-repetition maximum test; 3RM: three repetition maximum test; IMTP: Isometric mid-thigh pull; PF: peak force; D: Dominant side; ND: Non-dominant side; CODD: Change of direction deficit; Slalom run: consecutive multiple change of directions less than 90°. All change of direction performances were expressed as the time to complete the task in seconds.

Maximum strength

Eleven studies evaluated the relationship between maximal effort multi-joint lower body strength movements and CODP, with the 1-repetition maximum back squat being the most frequently used strength test. Five[25,28,31,35-36] of these eleven found meaningful relationships where greater strength was associated with improved CODP, while six[29-30,32-34,37] found non-meaningful relationships between maximal strength and CODP.

Two [23,31] of the five studies that demonstrated practically meaningful relationships between maximal dynamic strength and CODP made use of relative strength, normalised to body mass, and two[20,26] made use of absolute values as their performance variable for the maximum strength test. Spiteri et al.[30] evaluated both relative and absolute strength values. Apart from Spiteri and colleagues[30], who used isometric movements, all studies that revealed meaningful relationships utilized dynamic moments for their maximal strength tests. Four[29-30,32,37] of the six studies that found non-meaningful relationships evaluated absolute strength as their maximal strength performance variables. Ranisavljev et al.[33] and Scanlan et al.[34] made use of both absolute and relative strength as their desired performance variable for the maximal strength test. Three[29,32-33] studies made use of dynamic movements, while the remaining three[30,34,37] made use of isometric movements during their maximal strength testing battery.

Two[25,31] of the five meaningful studies used tasks with single directional changes as their COD test and two[28,36] used tasks with multiple directional changes as their COD test. Spiteri et al. [30] utilized COD tests with both single and multiple directional changes. Delaney et al.[29] was the only non-meaningful study that used a COD task with single directional changes as their COD test, while the remaining five[25,27-29,32] made use of COD tasks with multiple directional changes.

Table 3. Relationship between lower body ballistic movements and change of direction performance.

Authors	Athletes	What was compared	Ballistic vs COD r-value	p-value	Magnitude
Alemdaroglu[38]	12 male basketball players aged: 25.1 ± 1.7 years	CMJ-height vs T-test SJ-height vs T-test	CMJ-height vs. T-test = -0.59 SJ-height vs. T-test = -0.47	$p < 0.05$ $p < 0.05$	large moderate
Barnes et al.[39]	29 female collegiate volleyball players aged 20 ± 1.5 years	CMJ-height vs 3 x 180° cut	CMJ-height vs. 3 x 180° cut = -0.58	$p < 0.01$	large
Bourgeois et al.[28]	17 collegiate American football players aged: 20.5 ± 1.3 years	CMJ-height vs T-test CMJ-height vs Pro-agility test BJ vs T-test BJ vs Pro-agility test	CMJ-height vs T-test = -0.59 CMJ-height vs Pro-agility =-0.56 BJ vs T-test = -0.68 BJ vs Pro-agility =-0.58	$p < 0.05$ $p < 0.05$ $p < 0.05$ $p < 0.05$	large large large large
Collins et al.[40]	15 youth American football players aged: 15.93 ± 0.96 years	DBT-average velocity vs Pro-agility test DBT-peak velocity vs Pro-agility test	Average velocity vs. Pro-agility = -0.27 Peak velocity vs. Pro-agility = -0.16	$p = 0.334$ $p = 0.565$	small small
Delaney et al.[29]	31 male professional rugby league players aged 24.3 ± 4.4 years	40 kg CMJ-PP vs 505	D = -0.13 ND = -0.12	$p > 0.05$ $p > 0.05$	small small
Falch et al.[41]	23 male football players aged 22.5 ± 2.6 years	Single CMJ-height vs 45° cut Single CMJ-height vs 505	Single CMJ-height vs 45° = -0.49 Single CMJ-height vs 505 = -0.08	$p < 0.05$ $p > 0.05$	moderate trivial
Los Arcos et al.[42]	118 male soccer players aged 16.5 ± 3.0 years	CMJ-height vs T-test	CMJ vs T-test = 0.70	$p < 0.001$	very large

Authors	Athletes	What was compared	Ballistic vs COD r-value	p-value	Magnitude
Markovic[30]	76 physical education students aged 20.7 ± 1.7 years	BJ vs Slalom run SJ-P/BM vs Slalom run	BJ vs Slalom run = -0.12 SJ-P/BM vs Slalom run = -0.33	$p > 0.05$ $p > 0.05$	small moderate
Meylan et al.[43]	44 males aged 20.9 ± 4.5 years, 36 females aged 19.7 ± 2.0 years	Single CMJ-height vs 2x180° cut Single BJ vs 2x180° cut	Men Single CMJ-height vs 2x180° = -0.41 Women Single CMJ-height vs 2x180° = -0.52 Men Single BJ vs 2x180° = -0.46 Women Single BJ vs 2x180° = -0.59	$p < 0.01$ $p < 0.01$ $p < 0.01$ $p < 0.01$	moderate large moderate large
Michailidis et al.[44]	441 youth soccer players aged 9 to 16 years	Single CMJ-height vs 505 Single CMJ-height vs Arrowhead Single BJ vs 505 Single BJ vs Arrowhead	U/10 Single CMJ-height vs Arrowhead = 0.11 Single BJ vs Arrowhead = 0.02 Single CMJ-height vs 505 = 0.04 Single BJ vs 505 = 0.12 U/15 Single CMJ-height vs Arrowhead = -0.21 Single BJ vs Arrowhead = 0.07 Single CMJ-height vs 505 = 0.54 Single BJ vs 505 = 0.27	 $p = 0.756$ $p = 0.261$ $p = 0.906$ $p = 0.732$ $p = 0.382$ $p = 0.770$ $p = 0.017$ $p = 0.268$	 small trivial trivial small small trivial large small

Authors	Athletes	What was compared	Ballistic vs COD r-value	p-value	Magnitude
Negra et al.[45]	95 competitive level male soccer players aged 12.3 ± 0.9 years 92 competitive level male handball players aged 12.5 ± 1.7 years	CMJ-height vs Illinois CMJ-height vs T-test SJ-height vs Illinois SJ-height vs T-test	Soccer CMJ vs Illinois = -0.67 CMJ vs T-test = -0.58 SJ vs Illinois = -0.64 SJ vs T-test = -0.53 Handball CMJ vs Illinois = -0.58 CMJ vs T-test = -0.69 SJ vs Illinois = -0.47 SJ vs T-test = -0.60	 p = 0.001 p = 0.001 p = 0.001 p = 0.001 p = 0.001 p = 0.001 p = 0.001 p = 0.001	 large large large large large large moderate large

Authors	Athletes	What was compared	Ballistic vs COD r-value	p-value	Magnitude
Nimphius et al.[31]	10 female softball players aged 18.1 ± 1.6 years	CMJ-height vs 505 JS-PF vs 505	Pre-season: CMJ-heigh vs ND = -0.23 CMJ-height vs D = -0.35 JS-PF vs D = -0.64 JS-PF vs ND = -0.33 Mid-season: CMJ-heigh vs ND = -0.45 CMJ-height vs D = -0.31 JS-PF vs D = -0.57 JS-PF vs ND = -0.74 Post-season: CMJ-heigh vs ND = -0.30 CMJ-height vs D = -0.48 JS-PF vs D = -0.39 JS-PF vs ND = -0.56	 p > 0.05 p > 0.05 p > 0.05 p > 0.05 p > 0.05 p > 0.05 p > 0.05 p < 0.05 p > 0.05 p > 0.05 p > 0.05 p > 0.05	 small moderate large moderate moderate moderate large very large moderate moderate moderate large
Ranisavljev et al.[33]	30 males aged 20.7 ± 1.3 years	CMJ-PP vs T-test CMJ-height vs T-test	CMJ-PP vs T-test = -0.40 CMJ-height vs T-test= -0.50	p = 0.028 p = 0.005	moderate moderate

Authors	Athletes	What was compared	Ballistic vs COD r-value	p-value	Magnitude
Rouissi et al.[46]	31 young elite soccer players aged 17.4 ± 0.6 years	BJ distance? vs 45° cut total time? BJ vs 90° cut BJ vs 135° cut BJ vs 505	BJ vs 45° cut -D = 0.25 BJ vs 45° cut -ND = 0.03 BJ vs 90° cut -D = 0.13 BJ vs 90° cut -ND = 0.13 BJ vs 135° cut -D = -0.11 BJ vs 135° cut -ND = 0.11 BJ vs 505 -D = -0.03 BJ vs 505 -ND = 0.01	$p > 0.05$ $p > 0.05$ $p > 0.05$ $p > 0.05$ $p > 0.05$ $p > 0.05$ $p > 0.05$ $p > 0.05$	small trivial small small small small trivial trivial
Scanlan et al.[34]	24 male adolescent basketball players aged 16 to 18 years	CMJ-PF vs T-test CMJ-PFrel vs T-test BJ vs T-test	CMJ-PF vs T-test = -0.36 CMJ-PFrel vs T-test = -0.63 BJ vs T-test = -0.67	$p = 0.087$ $p = 0.001$ $p < 0.001$	moderate large large
Schultz et al.[47]	16 elite snow sport athletes aged 25 ± 7 years 9 male, 7 female	CMJ-height vs Z-Z SJ-height vs Z-Z JS-MPP vs Z-Z JS-average velocity vs Z-Z	CMJ-height vs Z-Z = 0.83 SJ-height vs Z-Z = 0.79 JS-MPP vs Z-Z = 0.77 JS-average velocity vs Z-Z = 0.76	$p < 0.01$ $p < 0.01$ $p < 0.01$ $p < 0.01$	very large very large very large very large

Authors	Athletes	What was compared	Ballistic vs COD r-value	p-value	Magnitude
Sisic et al.[48]	92 junior basketball players aged 16 to 17 years	BJ vs T-test BJ vs Z-Z BJ vs 505 Sargent Jump vs T-test Sargent Jump vs Z-Z Sargent Jump vs 505	BJ vs T-test =-0.51 BJ vs Z-Z =-0.46 BJ vs 505 =-0.51 Sargent Jump vs T-test =-0.52 Sargent Jump vs Z-Z =-0.54 Sargent Jump vs 505 =-0.55	$p < 0.05$ $p < 0.05$ $p < 0.05$ $p < 0.05$ $p < 0.05$ $p < 0.05$	large moderate large large large large
Spiteri et al.[35]	12 female basketball players aged 24.3 ± 2.6 years	CMJ-P/BM vs 505 CMJ-P/BM vs T-test	CMJ-P/BM vs 505 = -0.17 CMJ-P/BM vs T-test = -0.47	$p > 0.01$ $p > 0.01$	small moderate
Swinton et al.[36]	30 nonprofessional rugby union players aged 24.2 ± 3.9 years	CMJ-height vs 505	CMJ-height vs 505 = -0.54	$p < 0.01$	large
Yanci et al.[49]	255 youth runners aged 7 to 16 years 116 males, 139 females	BJ vs 505 BJ vs T-test	BJ vs 505 = -0.60 BJ vs T-test = -0.76	$p < 0.01$ $p < 0.01$	large very large

Authors	Athletes	What was compared	Ballistic vs COD r-value	p-value	Magnitude
Yanci et al.[50]	39 male soccer players aged 22.9 ± 2.8 years.	SJ-height vs 505 SJ-height vs Pro-agility test SJ-height vs T-test CMJ-height vs 505 CMJ-height vs Pro-agility test CMJ-height vs T-test BJ vs 505 BJ vs Pro-agility test BJ vs T-test	SJ-height vs 505 = -0.53 SJ-height vs Pro-agility test = -0.41 SJ-height vs T-test = -0.25 CMJ-height vs 505 = -0.60 CMJ-height vs Pro-agility test = -0.47 CMJ-height vs T-test = -0.34 BJ vs 505 = -0.51 BJ vs Pro-agility test = -0.38 BJ vs T-test = -0.69	$p < 0.01$ $p < 0.05$ $p > 0.05$ $p < 0.01$ $p < 0.05$ $p > 0.05$ $p < 0.01$ $p < 0.05$ $p < 0.01$	large moderate small large moderate moderate large moderate large

Abbreviations: CMJ: Countermovement jump; PP: Peak power; P/BM: Relative power; PF: Peak force; PFrel: Relative peak force; BJ: Broad jump; SJ: Squat jump; MPP: Mean propulsive power; JS: Jump squat; Z-Z: Zig-Zag agility test; D: Dominant side; ND: Non-dominant side; DBT: Drive block test (American football position-specific test); Slalom run: consecutive multiple change of directions less than 90°. All change of direction performances were expressed as the time to complete the task in seconds.

Ballistic strength

Twenty-one studies assessed the relationship between ballistic strength and CODP, with most studies (16/21) utilizing the countermovement jump to assess ballistic strength. Fourteen[28,31,33-34,36,38-39,42-43,45,47-50] of these found meaningful relationships, three[30,35,41] studies had mixed results, while four[29,40,44,46] studies found non-meaningful relationships.

Only four[31,33-34,47] of the fourteen studies that showed meaningful relationships used a biomechanical measure derived from force-time data (i.e. peak force, peak power, etc) to measure ballistic strength capabilities, the remaining ten studies used the jump performance outcome (i.e. jump height and jump distance). All the studies that showed meaningful relationships between ballistic strength and CODP used absolute values as their performance variable for their ballistic strength task, except for Scanlan and colleagues[34], who used both relative and absolute values. The three studies that showed mixed relationships used distance covered during the jump[41], a force-derived value[35], and both a force-derived value and distance covered during the jump[30] to measure ballistic strength capabilities. Respectively, one[41] study used absolute values, one[35] study used relative values, and one[30] study used both absolute and relative values as their performance variables for the ballistic strength task. Two[44,46] of the four studies that found non-meaningful relationships used distance covered during the jump, while the other two[29,40] used a force value to measure ballistic strength capabilities. All four[29,40,44,46] used absolute values as their performance variable for their ballistic strength task.

Two[31,36] studies that found meaningful relationships used tasks with single directional changes as their COD test, nine[28,33-34,38-39,42-43,45,47] studies used tasks with multiple directional changes as their COD test, while three[43-45] studies used both single and multiple directional changes during their COD tests. One[41] study of those that showed mixed relationships utilized single directional changes during their COD test, one[30] study used multiple directional changes during their COD test, while one[35] study used both single and multiple directional changes. Of the studies that found non-meaningful relationships between ballistic strength and CODP, two[29,46] utilized single directional changes, one[40] study used multiple directional changes, and one[44] study used both single and multiple directional changes during their COD tasks.

Table 4. Relationship between lower body plyometric movements and change of direction performance.

Authors	Athletes	What was compared	Plyometric vs COD r-value	p-value	Magnitude
Barnes et al.[39]	29 female collegiate volleyball players aged 20 ± 1.5 years	DJ30-height vs 3x180° test DJ30-RSI vs 3x180° test	DJ30-height vs 3x180° test = -0.320 DJ30-RSI vs 3x180° test = -0.223	$p > 0.05$ $p > 0.05$	moderate small
Delaney et al.[29]	31 male professional rugby league players aged 24.3 ± 4.4 years	DJ30-RSI vs 505	DJ30-RSI vs 505 D = -0.44 DJ30-RSI vs 505 ND = -0.45	$p < 0.05$ $p < 0.05$	moderate moderate
Falch et al.[41]	23 male football players aged 22.5 ± 2.6 years	DJopt-RSI vs 45° cut DJopt-RSI vs 505	DJopt-RSI vs 45° = -0.542 DJopt-RSI vs 505 = -0.356	$p < 0.05$ $p > 0.05$	large moderate
Hirose et al.[51]	135 female football players aged 12 to 25	5-step bound vs 10m x 5 COD test	5-step bound vs 10m x 5 COD = -0.44	$p < 0.01$	moderate
Maloney et al.[52]	18 healthy males aged 22 ± 4 years	DJ18-height vs double cut DJ18-RSI vs double cut	DJ18-height vs double cut = -0.319 DJ18-RSI vs double cut = -0.337	$p = 0.197$ $p = 0.172$	moderate moderate
Markovic et al.[30]	76 physical education students aged 20.7 ± 1.7 years	Hopping-PP vs Slalom run Hopping-PP vs Pro-agility	Hopping vs Slalom run = -0.26 Hopping vs Pro-agility = -0.3	$p > 0.05$ $p > 0.05$	small moderate
Meylan et al.[43]	44 males aged 20.9 ± 4.5 years, 36 females aged 19.7 ± 2.0 years	Single LJ vs 2x180° cut	Men Single LJ vs 2x180° = -0.288 Women Single LJ vs 2x180° = -0.399	$p > 0.05$ $p > 0.05$	small moderate

Authors	Athletes	What was compared	Plyometric vs COD r-value	p-value	Magnitude
Michailidis et al.[44]	441 youth soccer players aged 9 to 16 years	Single TJ vs 505 Single TJ vs Arrowhead	U/10 Single TJ vs Arrowhead = 0.657 Single TJ vs 505 = 0.283 U/15 Single TJ vs Arrowhead = -0.341 Single TJ vs 505 = 0.552	 p = 0.039 p = 0.429 p = 0.154 p = 0.114	 large small moderate large
Miki et al.[53]	102 male athletes	Single RJ-height vs Pro-agility test Single RJ-height vs T-test	RJ-D vs Pro-agility r=-0.659 RJ-ND vs Pro-agility r=-0.380 RJ-D vs T-test =-0.672 RJ-ND vs T-test =-0.244	p < 0.05 p < 0.05 p < 0.05 p < 0.05	large moderate large small
Negra et al.[45]	95 competitive level male soccer players aged 12.3 ± 0.9 years 92 competitive level male handball players aged 12.5 ± 1.7 years	5JT vs Illinois 5JT vs T-test	Soccer 5JT vs Illinois = -0.71 5JT vs T-test = -0.61 Handball 5JT vs Illinois = -0.72 5JT vs T-test = -0.80	 p = 0.001 p = 0.001 p = 0.001 p = 0.001	 very large large very large very large

Authors	Athletes	What was compared	Plyometric vs COD r-value	p-value	Magnitude
Rouissi et al.[46]	31 young elite soccer players aged 17.4 ± 0.6 years	5JT vs 45° cut 5JT vs 90° cut 5JT vs 135° cut 5JT vs 505	5JT vs 45° cut -D = 0.15 5JT vs 45° cut -ND = -0.02 5JT vs 90° cut -D = 0.03 5JT vs 90° cut -ND = -0.18 5JT vs 135° cut -D = 0.01 5JT vs 135° cut -ND = 0.11 5JT vs 505 -D = 0.17 5JT vs 505 -ND = 0.04	$p > 0.05$ $p > 0.05$ $p > 0.05$ $p > 0.05$ $p > 0.05$ $p > 0.05$ $p > 0.05$ $p > 0.05$	small trivial trivial small trivial small small trivial
Scanlan et al.[34]	24 male adolescent basketball players aged 16 to 18 years	1-step CMJ-height vs T-test RLBT vs T-test	1-step CMJ-height vs T-test = -0.18 RLBT vs T-test = -0.18	$p = 0.40$ $p = 0.40$	small small
Yanci et al.[50]	39 male soccer players aged 22.9 ± 2.8 years.	DJ20-height vs 505 DJ20-height vs Pro-agility test DJ20-height vs T-test 4BT vs 505 4BT vs Pro-agility test 4BT vs T-test	DJ20-height vs 505 = -0.57 DJ20-height vs Pro-agility test = -0.49 DJ20-height vs T-test = -0.37 4BT vs 505 = -0.46 4BT vs Pro-agility test = -0.26 4BT vs T-test = -0.54	$p < 0.01$ $p < 0.01$ $p > 0.05$ $p < 0.05$ $p > 0.05$ $p < 0.01$	large moderate moderate moderate small large

Authors	Athletes	What was compared	Plyometric vs COD r-value	p-value	Magnitude
Young et al.[18]	15 males aged 18 to 28 years	DJ30-RSI vs 20° cut	DJ30-RSI vs 20°L = -0.50	$p > 0.05$	large
			DJ30-RSI vs 20°R = -0.65	$p < 0.05$	large
		DJ30-RSI vs 40° cut	DJ30-RSI vs 40°L = -0.40	$p > 0.05$	moderate
			DJ30-RSI vs 40°R = -0.53	$p < 0.05$	large
		DJ30-RSI vs 60° cut	DJ30-RSI vs 60°L = -0.31	$p > 0.05$	moderate
			DJ30-RSI vs 60°R = -0.35	$p > 0.05$	moderate
		DJ30-RSI vs 4x60° cut	DJ30-RSI vs 4x60° = -0.54	$p < 0.05$	large

Abbreviations: DJ30: 30cm box height drop jump; RSI: Reactive strength index; DJopt: Optimal box height drop jump; DJ18: 18cm box height drop jump; DJ20: 20cm box height drop jump; 5JT: five jump test; RLBT: Repeated lateral bound test; TJ: Tripple jump; RJ: Rebound jump; LJ: Lateral jump; PP: Peak power; 4BT: 4 bounce test; CMJ: Countermovement jump; D: Dominant side; ND: Non-dominant side; Slalom run: consecutive multiple change of directions less than 90°. All change of direction performances were expressed as the time to complete the task in seconds.

Plyometric strength

Fourteen studies assessed the relationship between plyometric strength and CODP. Nine[18,29,41,44-45,50-53] of these found meaningful relationships, three[30,39,43] studies had mixed results, while two studies[34,46] found non-meaningful relationships.

Five[44-45,50-51,53] of the studies that found meaningful relationships used a measure of distance covered during the jumping task, three[18,29,41] used a measure of the force produced during the jumping tasks, and one[52] used both a measure of distance covered and force produced during the jumping tasks. All nine studies used absolute values as their performance variable for their plyometric strength task. One[43] study that showed mixed relationships used distance covered during the jump, one[30] study used a measure of force during the jump, and one[39] study used both distance covered and a measure of force output during the jumping tasks. All three studies used absolute values as their performance variables for plyometric strength. Both[34,46] studies that found non-meaningful relationships also used distance covered during the jumping task as their measure of plyometric strength. Similarly, both studies used absolute values as their performance variables for the plyometric tasks.

Two[29,41] studies that found meaningful relationships used single directional change tasks, four[45,51-53] studies used multiple directional change tasks, and three[18,44,50] used both single and multiple directional change tasks for their COD tests. All[30,39,43] studies that revealed mixed relationships utilized COD tasks that required multiple directional changes. Of the studies that found non-meaningful relationships between plyometric strength and CODP, one[46] used COD tasks that require single directional changes, and the other one[34] used COD tasks that require multiple directional changes.

Table 5. Training effect of strength-, ballistic-, and plyometric training interventions on change of direction performance.

Authors	Athletes	COD tests used + measures	Intervention	What was compared	Strength on COD ES	Magnitude	Ballistic and plyometric on COD ES	Magnitude
Appleby et al.[54]	49 male rugby players aged: 22.4 ± 4.1 years	50° COD task [time(s)]	6 weeks of: Bilateral training using a back squat vs Unilateral training using step-ups	Pre vs Post	Bilateral = -0.90 Unilateral = -0.54	moderate small		
Banyard et al.[55]	24 males aged 26 ± 5 years	505 test [time(s)]	6 weeks of: Velocity based loading vs % of 1RM based loading	Pre vs Post	VBT on D = -1.20 VBT on ND = -1.27 PBT on D = -0.86 PBT on ND = -0.86	large large moderate moderate		
Davies et al.[56]	44 female youth aged 11 to 14 years	Pro-agility test [time(s)]	7 weeks of plyometric training for: mid-peak height velocity vs post-peak height velocity	Pre vs Post			Mid-PHV = 0.05 Post-PHV = -0.73	trivial moderate

Authors	Athletes	COD tests used + measures	Intervention	What was compared	Strength on COD ES	Magnitude	Ballistic and plyometric on COD ES	Magnitude
De Hoyo et al.[57]	32 late adolescent Spanish soccer players aged 18 ± 1 years	Zig-Zag COD test [completion time(s)]	8 weeks of: Full squat vs Resisted sprinting vs Plyometric	Pre vs Post	Full squat= 0.15	trivial	Plyometric = 0.02	trivial
De Hoyo et al.[58]	32 physically active males aged 22 ± 2 years	Zig-Zag COD test [total time(s)]	6 weeks of: Vertical resistance training vs Horizontal resistance training	Pre vs Post	Vertical = -0.08 Horizontal = 0.04	trivial trivial		
Freitas-Junior et al.[59]	15 male volleyball players aged 22 ± 1 years	T-test [time(s)]	6 weeks of weighted vest plyometric training	Pre vs Post			Plyometric = 0.79	moderate

Authors	Athletes	COD tests used + measures	Intervention	What was compared	Strength on COD ES	Magnitude	Ballistic and plyometric on COD ES	Magnitude
Gonzalo-Skok et al.[60]	18 male basketball players aged 16.8 ± 1.9 years	V-cut test [time(s)] 180° cutting test [time(s)]	6 weeks of: Unilateral training vs Bilateral training	Pre vs Post	Unilat on V-cut = 0.28 Bilat on V-cut = 0.26 Unilat on 180° R = 0.43 Unilat on 180° L = 0.48 Bilat on 180° R = 0.41 Bilat on 180° L = 0.02	small small small small small trivial		
Hale et al.[61]	15 female youth volleyball players aged 15.1 ± 2.7 years	9-cone test [time(s)]	8 weeks of: strength and plyometric training	Pre vs Post	0.871	moderate		
Hammami et al.[62]	28 elite-level female handball players aged 16.6 ± 03 years	Half T-test [time(s)] Modified Illinois test [time(s)]	10 weeks of: Complex strength training vs Control	Intervention vs Control	Half T-test= 0.09 Illinois = 0.10	trivial trivial		

Authors	Athletes	COD tests used + measures	Intervention	What was compared	Strength on COD ES	Magnitude	Ballistic and plyometric on COD ES	Magnitude
Hammami et al.[63]	28 male soccer players aged 16.4 ± 0.6 years	4x5-m sprint [time(s)] 9-3-6-3-9 agility test [time(s)]	8 weeks of: Contrast strength training vs Control	Intervention vs Control	4x5-m = 0.15 180° cuts = 0.13	trivial trivial		
Jlid et al.[64]	28 male soccer players aged 11.7 ± 0.4 years	T-Test [time(s)]	8 weeks of: Multidirectional plyometric vs Control	Intervention vs Control			Multidirectional plyometrics = 3.53	very large
Loturco et al.[65]	22 male professional soccer players aged 22.0 ± 2.4 years	Zig-Zag COD test [time(s)]	5 weeks of: Optimal load + plyometrics vs Optimal load + resisted sprinting	Pre vs Post			plyometric = -0.87	moderate

Authors	Athletes	COD tests used + measures	Intervention	What was compared	Strength on COD ES	Magnitude	Ballistic and plyometric on COD ES	Magnitude
Makhlouf et al.[66]	57 male elite-level soccer players aged 13.7 ± 0.5 years	15-m run agility test [time(s)]	12 weeks of: Strength before endurance vs Endurance before strength vs Strength and endurance on separate days	Pre vs Post	S-E = 0.03 E-S = 0.18 S&E = 0.30	trivial trivial small		
Nimphius et al.[25]	10 female softball players aged 18.1 ± 1.6 years	505 test [time(s)]	20 weeks of in-season training	Pre vs Post	D = -0.43 ND = -0.81	small moderate		
Ramirez-Campillo et al.[67]	18 young male soccer players aged 17.3 ± 1.1 years	T-test [time(s)]	8 weeks of: Unilateral plyometric training vs Bilateral plyometric training	Pre vs Post			Unilat = 0.41 Bilat = 0.66	small moderate

Authors	Athletes	COD tests used + measures	Intervention	What was compared	Strength on COD ES	Magnitude	Ballistic and plyometric on COD ES	Magnitude
Ramirez-Campillo et al.[68]	73 young male soccer players aged: 11 to 16 years	Illinois test [total time(s)]	7 weeks of: 30-cm box height drop jumps vs Optimal RSI box height drop jumps	Pre vs Post			30-cm = -0.21 optimal = -0.34	small small
Ramirez-Campillo et al.[69]	23 amateur female soccer players aged 21.4 ± 3.2 years	Meylan COD test [time(s)]	8 weeks of: 1 session per week vs 2 sessions per week	Pre vs Post			1 per week = 1.68 2 per week = 1.16	large moderate
Sanchez-Sanchez et al.[70]	24 male amateur team-sports players aged 22.5 ± 2.2 years	Illinois agility test [time(s)]	5 weeks of: HIIT vs HIIT + eccentric overload training	Pre vs Post	HIIT = 0.42 HIIT + EOT = 1.01	small moderate		

Authors	Athletes	COD tests used + measures	Intervention	What was compared	Strength on COD ES	Magnitude	Ballistic and plyometric on COD ES	Magnitude
Shalfawi et al.[71]	20 elite female soccer players aged 19.4 ± 4.4 years	9-3-6-3-9 agility test [time(s)]	10 weeks of: Strength training	Pre vs Post	Strength training = -0.1	trivial		
Singh et al.[72]	37 elite hockey players aged 23 ± 2.4 years	505 test [time(s)]	6 weeks of: high-to-low jumping vs low-to-high jumping	Pre vs Post			High-to-low = 0.06 Low-to-high = -0.03	trivial trivial
Yanci et al.[73]	44 male futsal players aged 22.5 ± 5.0 years	505 test [time(s)]	6 weeks of: 1 session per week vs 2 sessions per week	Pre vs Post			1 per week = -0.67 2 per week = -5.50	moderate very large
Yanci et al.[74]	16 male soccer players aged 22.5 ± 2.72 years	T-test [time(s)]	6 weeks of: 2 sets of everything vs 4 sets of everything	Pre vs Post			2 sets = 0.23 4 sets = 0.03	small trivial

Authors	Athletes	COD tests used + measures	Intervention	What was compared	Strength on COD ES	Magnitude	Ballistic and plyometric on COD ES	Magnitude
Zghal et al.[75]	31 pubescent soccer players aged 14.5 ± 0.5 years	505 test [time(s)]	7 weeks of: Plyometrics training vs Combined resistance and plyometric training	Pre vs Post	Combined = 0.31	small	Plyometric = 0.12	trivial

Abbreviations: Pre vs Post: Pre-intervention vs post-intervention within group; Intervention vs control: intervention group vs control group; VBT: velocity-based training; PBT: percentage-based training; PHV: peak height velocity; Unilat: Unilateral; Bilat: Bilateral; S-E: Strength day followed by endurance day; E-S: Endurance day followed by strength day; S&E: Strength followed immediately by endurance; HIIT: High-intensity interval training; EOT: Eccentric overload training; L: left leg; R: right leg; D: dominant side; ND: non-dominant side.

Training effects

Twenty-three studies evaluated training effects on CODP. Eleven[54-55,57-58,60-63,66,70-71] studies utilized maximal strength training interventions, eleven[56-57,59,64-65,67-69,72-74] utilized a combination of plyometric and ballistic training interventions, and in two[25,75] studies it was unclear whether maximal strength or the combination of ballistic and plyometric training was related to the results obtained.

Only two out of eleven studies reported meaningful effects of a maximal strength training intervention on CODP, with one[55] utilizing a single directional change test and the other[61] a multiple directional change test. Both studies utilized bilateral movements during their strength training intervention. Two studies showed mixed results following a maximal strength training intervention. One[54] study used single directional changes while the other[70] study used multiple directional changes tests. Appleby et al.[54] used both unilateral and bilateral movements during their maximal strength training intervention, while Sanchez-Sanchez et al.[70] used only bilateral movements. Seven[57-58,60,62-63,66,71] studies found non-meaningful results when evaluating the effect of maximal strength training interventions on CODP. All these studies utilized COD tests that require multiple directional changes and all but one[60] utilized bilateral movements only during their strength training intervention.

Four[59,64-65,73] of the eleven studies that examined the effect of ballistic and plyometric training interventions showed meaningful effects of CODP. Yanci et al.[73] utilized a COD task that requires a single directional change, while all other[59,64-65] studies used COD tasks that require multiple directional changes. All four of these studies used bilateral movements during their training interventions. Three[56,67,69] studies showed mixed results of which all of them used multiple directional change COD tests. Two[56,69] of these studies used bilateral movements during their training intervention, while one[67] study utilized both bilateral and unilateral movements. Four[57,68,72,74] studies found non-meaningful effects of ballistic and plyometric training on CODP. All four of these studies used COD tasks that require multiple directional changes as well as bilateral movements during their training intervention.

Two[25,75] studies were unclear of whether maximal strength or the combination of ballistic and plyometric training was the cause of the results obtained as their interventions contained all three modes of strength training. Nimphius et al.[25] mixed results following in-season training, while Zghal et al.[75] found non-meaningful effects following a combination of maximal strength, ballistic, and plyometric training.

Discussion

The purpose of this literature review was to critically evaluate the existing evidence for relationships between performance in COD tasks and lower limb strength qualities. A secondary aim was to critique the literature examining the effect of lower-body multi-joint muscular strength training interventions on CODP. The main findings from this literature search were that ballistic- and plyometric strength qualities relate strongly to CODP. There were, however, mixed results regarding the relationship between maximal strength and CODP with five of the eleven studies showing meaningful associations and the remaining six showing non-meaningful associations. A surprising find in this literature review was that there is limited evidence to show that training programs designed to improve maximal-, ballistic-, and plyometric strength affects CODP, suggesting that effective training interventions for improving CODP still requires investigation.

One of the challenges faced in reviewing the existing literature on this topic was that there are relatively few studies available assessing the relationship between lower body strength factors and COD tasks with single directional changes, especially those with COD angles of less than 180-degrees. Twenty-two studies included single directional change tests consisting of 180-degree turns, while only six studies included tests consisting of less than 180-degree turns. The lack of specificity during COD tasks with multiple directional changes is well known.[1] More turns during the COD task introduces more variables that contribute to the outcome measure (COD time) and the practitioner is unable to detect the exact mechanism that causes the slow or fast test time. Change of direction tasks of longer duration may also be influenced by fatigue, resulting in the test not being able to isolate COD ability, but rather being influenced by different energy systems. The COD angle determines how much momentum is maintained throughout the turn as well as the magnitude of deceleration and re-acceleration is required when approaching and exiting the turn respectively. The number of turns performed during the COD task could influence the entry velocity into each succeeding turn as the athlete has hardly finished accelerating out of the previous turn before they need to start decelerating going into the next turn. Multiple turns also require the athlete to turn using both legs, which makes it more complex to detect asymmetries between legs. The results from this literature review, where five studies that used multiple directional changes found non-meaningful relationships with maximal strength, could be explained by the use of different energy systems when completing the COD tasks compared to the maximal strength tasks. Change of direction tasks of longer duration may be subject to influences of energetics rather than just assessing COD ability.[1] There is a strong relationship between ballistic strength and CODP regardless of the number of turns involved during the COD task. The nature of a ballistic task is producing enough force to generate momentum thus allowing for the projecting of an object into free space. This allows the athlete to better manipulate the momentum going through a directional change that requires deceleration, a directional change, and reacceleration. Single directional changes are more specific to plyometric movements in the sense that they both require short periods of time to be completed and thus will be influenced by fatigue to a lesser degree. This is supported by the fact that only one study that utilized single directional change tests found a non-meaningful relationship, while five found meaningful relationships with plyometric strength. This emphasises the idea that the mechanisms required to overcome the inertia of the downward travelling centre of mass and the subsequent generation of enough force to accelerate the centre of mass enough to overcome inertia and propel the body into space in the opposite direction during a jumping motion are similar to those required to overcome inertia during a COD task.

Maximal strength and change of direction performance.

Currently, there is an unclear relationship between maximal strength and CODP in the literature, as half of the studies reviewed (5/11) revealed meaningful relationships, while the remainder (6/11) revealed non-meaningful relationships.

Studies that revealed non-meaningful relationships did not use relative strength while two studies that found meaningful relationships did use relative strength. A COD task requires the athlete to displace their centre of mass to successfully change movement direction. Enough force needs to be produced and applied to the ground by the athlete to decelerate, change movement direction, and reaccelerate again in the new direction. The higher the velocity into and out of the turn, the greater the deceleration and subsequent acceleration demands; thus, more force production is required. During a COD task, the forces needed to achieve these deceleration and acceleration requirements need to be enough to manipulate the momentum of the body mass. This reasoning provides key insight as to why producing large amounts of force relative to body mass would be beneficial to CODP. Although there is limited research available on the relationship between relative measures of maximal strength and CODP, all studies that evaluated this relationship found it to be meaningful. There is, however, not enough literature available on the relationship between maximal strength relative to body mass and CODP to produce an informed conclusion, more research is needed.

An argument could also be made that the nature of the strength movement, i.e., dynamic movement or isometric movement, could influence the relationship with CODP. Isometric strength testing is done at the joint angle at which the athlete is able to produce the greatest amount of force possible.[76] Isometric strength allows the athlete to produce higher levels of force which relates to overcoming inertia during the braking and propulsion phase.[12] Dynamic strength is more specific to COD tasks as both movements involve a change in joint angles when a force is produced. Dynamic strength also requires the athlete to produce large amounts of force through an entire range which includes angles at which the muscle contraction might not be as efficient.[76] This allows for greater specificity as the athlete will be required to produce large amounts of force through a range of joint angles seen on the field and also during the COD task.[77] The desired maximal strength test should be selected based on both the ability to detect the highest level of force that the athlete is capable of producing as well as the specificity to the COD task. There are, however, different joint angles in play during a COD task compared to a back squat, COD tasks take athletes through different ranges than that required to squat. Isometric strength tests would likely be more beneficial when comparing the force production to that required during COD tasks.

Ballistic strength

Twenty-one studies evaluated the relationship between ballistic strength and CODP of which fourteen found meaningful relationships, indicating clear importance of ballistic strength during CODP from the literature.

Absolute measures of force output were the most used as performance variables during the ballistic strength movements throughout the literature. Only one of the fourteen studies that found meaningful relationships used force output as both absolute and relative measures for their performance variable during the ballistic strength movements. The remaining thirteen studies all used only absolute measures of force output. It is thus clear that the level of force production by the athlete is a contributing factor during COD tasks. A ballistic task, although on the opposite side of the force-velocity curve to maximal strength, requires high levels of force output to complete the task. High levels of force production are needed to change the athlete's velocity at two separate phases of the COD task. The first being during the deceleration phase where the athlete must decrease their running velocity going into the turn, and the second is the reacceleration phase where the athlete must increase their running velocity sprinting out of the turn.

Although it is seen as an absolute measure of ballistic strength, the distance covered during the jump incorporates some aspect of relative strength because the athlete must produce enough force to overcome inertia and increase the velocity of the entire mass of the body.

Plyometric strength

During a plyometric movement, the athlete is required to convert an eccentric muscle contraction into a powerful concentric muscle contraction with a typical contraction time of less than 250ms.[78] Similarly, during COD tasks the athlete decelerates (eccentric muscle contraction) into the turn, changes direction and then re-accelerates (concentric muscle contraction) out of the turn. There is a clear strong relationship between the performance of these two movements in the literature. Nine of the fourteen studies found moderate to very large relationships between plyometric movements and CODP. This could be due to the nature of plyometric movements which requires a quick conversion of eccentric muscle forces into concentric muscle forces and short ground contact time for the success of the movement, similar to what is required during fast COD tasks.

According to my knowledge, there is no research available on the relationship between plyometric strength relative to body mass and CODP. Force output during a plyometric test expressed relative to body mass, will add a valuable dimension to understanding the physical capacity of an athlete that appears to be related to performance in COD.

There is also value in measuring the force output during a plyometric task, as this allows the practitioner to determine the exact amount of force needed by the athlete to overcome the inertia of the downward travelling centre of mass and subsequently generate enough momentum to propel the body into free space in the opposite direction in a very short time. The actual biomechanical measures such as peak force and force relative to body mass could add valuable information to understanding the relationship with CODP rather than just jump performance data.

Training interventions and CODP

The majority of the studies that have investigated the effect of strength training interventions on CODP have shown no meaningful effect, thus, indicating that an effective strength training intervention to improve CODP is yet to be determined. Higher force production capabilities following a strength training intervention would theoretically allow the athlete to better overcome inertia during the deceleration and reacceleration phases of the COD task. The data from this literature review, however, indicates that maximal force production is less important than force production at high velocities. When the goal of the training session is to improve force production, it is desirable to generate as much force as possible as fast as possible.

Yanci et al.[73] showed that should the frequency of plyometric training sessions be increased from once per week to twice per week, there could be significant, very large (ES = 5.50) improvements in CODP. Jlid et al.[64] used multi-directional plyometrics as their exercise prescription and found significant, very large (ES = 3.53) improvements in CODP. This could be due to the athletes training in movement planes that mimic the COD task as opposed to uniplanar movements seen in vertical and horizontal plyometrics. These studies provide a strong argument for increasing the total volume per week of plyometric training to elicit a faster CODP and that plyometric movements are indeed important during CODP. The best practice of plyometric training to improve CODP is, however, unclear from literature and yet to be determined.

Two[25,75] studies were unclear as to whether maximal strength or the combination of ballistic and plyometric training was the cause of the results obtained. Nimphius et al.[25] showed mixed results following in-season training, while Zghal et al.[75] found non-meaningful effects following a combination of maximal strength, ballistic, and plyometric training.

Limitations

There were a few limitations to this literature review. Non-English articles could have had valuable information to add to our understanding of the influence of different strength factors on CODP. Some studies could not be retrieved since they were not available at the time that the literature search was conducted. This is not a full meta-analysis which means that all results in this review were taken directly from other studies with no further analyses done on their results. A variety of tests were used with a variety of outcome variables for both strength and COD measures by all authors and thus it is very hard to draw an accurate conclusion as different tests will have different outcomes.

Conclusion

This literature review presents enough evidence to conclude that isometric-, ballistic-, and plyometric strength may be related to COD performance, but there isn't enough information to clearly understand if different strength capacities are more beneficial for different COD tasks. With the results from this literature review, it is clear there is limited research on strength factors associated with single COD tasks and more so using single COD tasks with less than 180-degree angles. Using COD tasks with single directional changes allows the sport scientists to isolate the physical quality they are trying to assess. Change of direction angles of less than 90-degree are more specific to sports such as rugby, hockey, and soccer, thus strength and conditioning coaches will better be able to prescribe exercises that are specific to the demands of the sport. Thus, it would be useful to determine the effect of different types of lower body strength factors on COD tasks that require single directional changes at different angles.

Chapter 3: Experimental Study

Introduction

Changing direction at high velocities can lead to key moments that determine the outcome of a match in field and court sports.[4,19] Change of direction (COD) is a component of agility that is described as the ability to decelerate, change movement direction, and reaccelerate again where no immediate reaction to a stimulus is required.[1-4] Change of direction performance (CODP) is the holistic task that involves a sprint into the turn, directional change, and a sprint out of the turn and incorporates the mechanics associated with agility performance i.e. deceleration, directional change, and acceleration.[7] Assessing completion time only as a measure of performance from an agility test may mask deficiencies in COD ability.[7] An athlete with good acceleration ability but poor change of direction skill could still complete the task in a competitive time. Change of direction deficit (CODD) is used to provide a more isolated measure of the athlete's COD skill not influenced by linear sprinting ability.[6-9] Change of direction deficit is calculated subtracting by the time that a directional change requires from the time a pure linear sprint over equivalent distance requires.[7-8]

There are multiple tests available to assess CODP that include, but are not limited to, the 505 COD test, Pro-agility test, Illinois agility test, T-test, and the 45- and 90-degree cutting test. The choice of COD test is highly dependent on the COD needs of the sport being assessed. Some sports, such as cricket and netball, involve more 180-degree turns and would thus justify the use of a COD test that include 180-degree turns. Other sports, such as hockey and rugby, require mostly changes in direction that are 90-degrees and smaller.[5] Velocity maintained during a COD task is a determinant of CODP.[13,20-21] During a cutting task the athlete needs to produce adequate amounts of force to overcome inertia and accelerate the centre of mass in the new direction. Change of direction biomechanics is both angle- and velocity dependant, where there is a trade-off between the angle of directional change and the velocity maintained throughout the cutting task.[13] A sharper COD angle results in reduced approach and exit velocities and demands higher magnitudes force production to allow for the larger change of momentum. During a 180-degree turn (figure 3A), the athlete reduces their velocity to zero for a short period of time, before pushing off in the opposite direction. The athlete would then need to produce more force to accommodate the larger change in momentum. A 45-degree cutting task (figure 3C), however, allows some momentum to be maintained through the turn and thus a smaller change in momentum is required by the athlete. A 90-degree cutting task (figure 3B) would be in between the 180-degree and 45-degree COD tasks. This leads to the suggestion that different angles of cutting tasks require different strength training demands depending on how much momentum is maintained throughout the COD task.

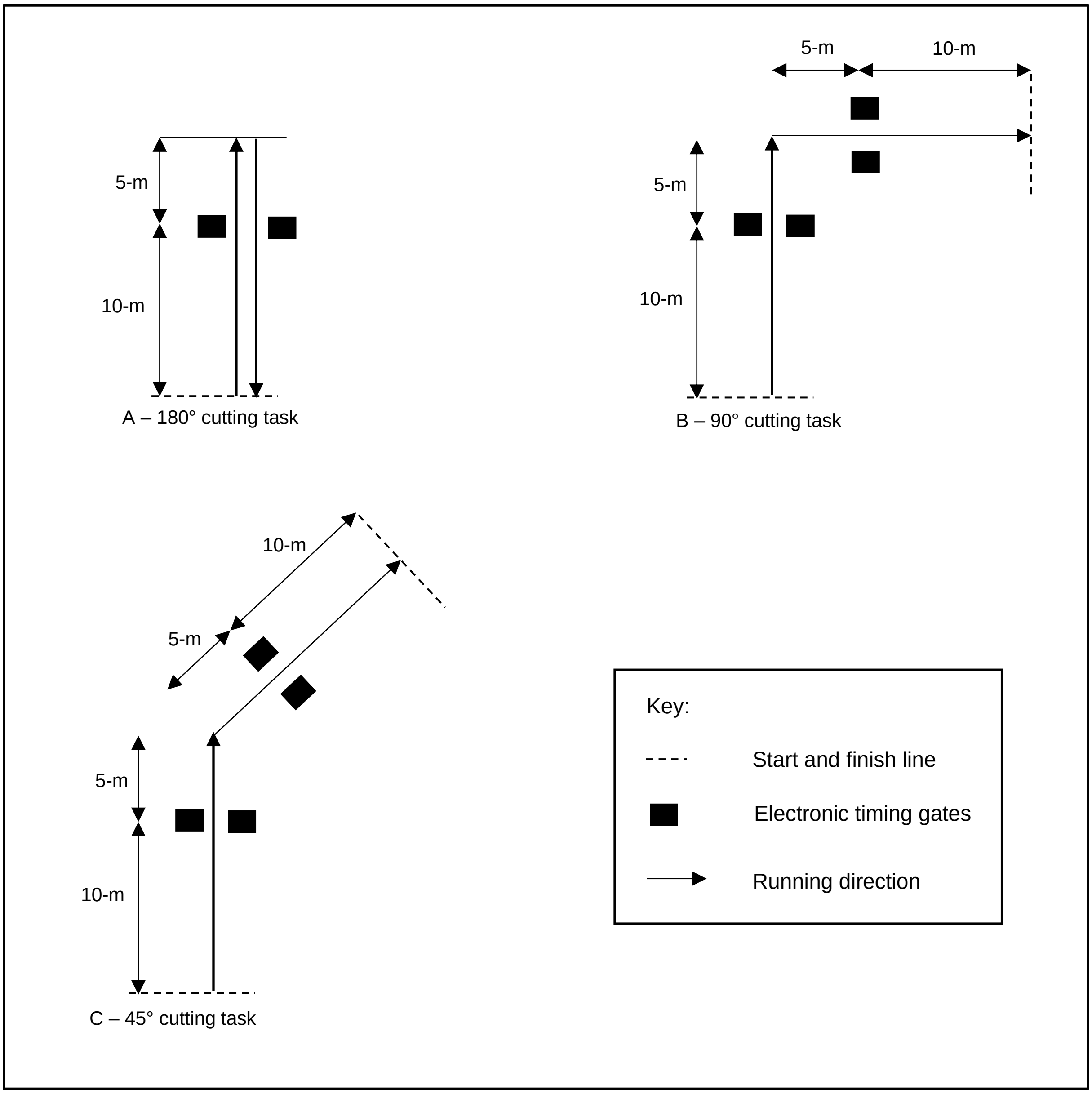

Figure 3: **A- 180° cutting task where the athlete momentarily comes to a complete stop before pushing off in the opposite direction. B- 90° cutting task where the athlete maintains some momentum through the directional change. C- 45° cutting task where little momentum is lost during the COD task due to the small angle of directional change.**

Lower limb strength is one of the many components that influence CODP. Strength is the ability to produce force against an external resistance.[14] Isometric strength is a maximal force production without a change in joint angles. Ballistic strength refers to jumping movements that require the athlete to exert as much force as possible in short periods of time with a slow stretch-shortening cycle (contraction time > 250ms).[16,22] Plyometric movements have been classified as jumping events with a fast stretch-shortening cycle (contraction time < 250ms) [22] and emphasize the loading of muscles during an eccentric muscle action, which is quickly followed by a rebound concentric action.[17] Reactive strength index is a calculated measurement to assess the ability of an athlete to utilize the stretch-shortening cycle as quickly as possible during jumping and hopping movements.[79]

Strength and conditioning coaches could find it useful to understand the relationship between CODP and isometric-, ballistic-, and plyometric strength to better be able to train the specific strength qualities required during a COD task. Knowledge of strength factors associated with lower cut angle COD tasks would allow practitioners to make informed decisions from COD tests that are more specific to the on-field demands of team sports. Thus, this study aimed to investigate the relationship between COD performance during 45-, 90-, and 180-degree cutting tasks and lower body isometric, ballistic, and plyometric strength.

Methods

Experimental approach

This study used a quantitative, cross-sectional study design to assess the relationship between lower body maximal-, ballistic-, and plyometric strength and CODP at different angles.

Athletes

Forty-five athletes that consisted of male high school rugby players (n = 20, age = 16.8 ± 1.1 years, height = 175.6 ± 8.1 cm, mass = 82.5 ± 14.7 kg), male university-level hockey players (n = 12, age = 20.5 ± 1.7 years, height = 177.0 ± 5.1 cm, mass = 71.3 ± 6.8 kg), and female university-level hockey players (n = 13, age = 20.6 ± 1.5 years, height = 164.4 ± 6.6 cm, mass = 61.2 ± 7.9 kg). The effect size achieved was larger than the priori power calculation, which is based on the smallest worthwhile effect (ES = 0.2), therefore the current sample size is sufficient to detect the effect. The ethics committee at the University of Pretoria approved this study (REC number 600/2020, Annexure A & B) as well as the umbrella study (REC number 83/2016, Annexure C). All athletes and associated information were handled in line with the regulations stated in the declaration of Helsinki (Annexure D). Adult athletes provided informed consent (Annexure E) before participation, while all athletes younger than 18 years of age completed a youth ascent form (Annexure F) as well as had their parent/guardian complete a parent consent form (Annexure G).

Testing procedure

Testing was conducted on separate days for the men's hockey, women's hockey, and rugby players. All testing for each group was completed within one day. Any trials performed with inappropriate technique according to the researcher were discarded and had to be completed again. Testing was divided into lab-based testing (isometric squat, countermovement jump, and 10-to-5 repeated jump test) and field-based testing (20-m sprint, 505 change of direction test, 90-degree cutting task, and 45-degree cutting task). Athletes wore comfortable training clothes with the appropriate footwear (trainers for lab-based testing and sport-specific boots for field-based testing). Lab-based tests were conducted in the biomechanics laboratory at the University of Pretoria (Annexure H). Field-based testing was done on the University of Pretoria's rugby field and hockey astroturf for rugby and hockey players respectively (Annexure I). A standardized warm-up consisting of dynamic stretches was conducted before the lab-based testing and a separate standardized warm-up was conducted before the onset of the field-based testing. The warm-up was followed by submaximal efforts of each test in the testing battery to ensure the athletes were familiar with the movements.

The testing battery for the lab-based tests was completed in the following order with at least three minutes rest between each test: Isometric squat, countermovement jump, and 10-to-5 repeated jump test. Force plates (JM6090-06, Bertec, USA) were utilized for the lab-based tests and were zeroed before each subject got on to the force plate for each test. Athletes were instructed to stand as still as possible on the force plates before the onset of all movements to record their weight. Electronic timing gates (SmartSpeed, Fusion Sport, Australia) were used to time the athletes during field-based tests. Field-based testing started with the 20-m linear sprint, then the 505 COD test, then the 90-degree cutting test, and concluded with the 45-degree cutting task with at least three minutes rest between tests. For all speed and COD tests, the athletes were instructed to start from a two-point start 0.5-m from the first set of timing gates and then run as fast as they can, on their own time, through all the gates to a marker placed 2-m behind the last timing gate. A CODD variable was calculated for all COD tasks by subtracting the time the athlete spent between 10-m and 20-m of the linear sprint from the time to complete the COD task. The 10-m to 20-m time during the linear sprinting task was selected as this allowed for the 10 m run into the cut during the COD tasks. An instantaneous speed measurement was also recorded by placing a timing gate 5-m before the starting gate. The time it takes during the 5-m leading up to the test was recorded as a value of instantaneous speed time. This measurement was compared with the 5-m to 10-m time during the 20-m sprint and was used as an inclusion criterion for the COD task. The average of the best two trials was used for statistical analyses in all tests used to allow for more reliable results. The within-participant coefficient of variation (CV) was calculated between all three trials for each test.

Isometric squat

The isometric squat was chosen as the isometric strength measure for this protocol. The isometric squat is a test used to measure the maximal amount of force an athlete can produce without a change in joint angles. Athletes were asked to step onto the force plates and squat to a depth where hip and knee angles are approximately 120- to 130-degrees as measured by a goniometer. A bar was then fixed at a height where it sits across the back of the shoulders, and the hands rest comfortably on the bar. Instructions to the athletes were to “push upwards as hard and as fast as you can”, “drive your feet into the ground and the bar from the floor”. The average peak force relative to body mass (F/BM_{ISQ}, CV = 4%) of the best two trials from the three trials completed was used for statistical analyses. This measurement analyses the maximal amount of force an athlete can produce without a change in joint angles in relation to their body mass.

Countermovement jump

The countermovement jump test was used to assess ballistic strength. Athletes performed the test with their hands akimbo and their feet shoulder-width apart. They were then instructed to bend quickly to a comfortable depth and immediately jump as fast and high as possible by extending their hips, knees, and ankles, keeping their hands on their hips throughout the jump. Three maximal effort jumps were performed with a rest period of about 30s between each jump. The average peak force (F_{CMJ}, CV = 2%), peak force relative to body mass (F/BM_{CMJ}, CV = 2%), RSI (RSI_{CMJ}, CV = 5%), take-off momentum (M_{CMJ}), and jump height (H_{CMJ}, CV = 3%) of the two trials with the highest jump height were recorded for statistical analyses. Jump was calculated from take-off velocity using the impulse-momentum method.

10-to-5 repeated jump test

The 10-to-5 repeated jump test was used to assess plyometric strength. The athletes stepped onto the force platform and got ready to jump with their feet shoulder-width apart and their hands akimbo. They then proceeded to perform a countermovement jump followed by 10 maximal rebound jumps[80-81] and were instructed to “jump as high as possible, while keeping your legs straight in the air”. Additionally, they were instructed to “imagine the ground is a hot surface”, and “imagine legs are like a stiff spring” which should result in the athlete jumping as high as possible with each jump. The highest five of the ten jumps were used to calculate the average of all the variables of interest. The average peak force relative to body mass (F/BM_{RJT}, CV = 4%), jump height (H_{RJT}, CV = 6%), and RSI (RSI_{RJT}, CV = 5%) of two trials was used for statistical analyses. Jump height was calculated from take-off velocity using the flight time method.

20-m linear sprint

Linear sprinting ability was assessed with the 20-m linear sprint (CV = 1%). Electronic timing gates were placed on 0-m, 5-m, 10-m, and 20-m. The exact distances were marked with cones using a 50-m measuring tape to ensure standardized distances for all groups. Two trials were completed, and the average times at the various distances were used for statistical analyses.

505 change of direction test

The 505 COD test (figure 3) assesses 180-degree cutting ability (CV = 2%). The test involves a 10-m sprint past a timing gate, a further 5-m sprint to a turning line where either the left or right foot, depending on the trial, is reached out and planted on or over the turning line before a 180-degree cut is performed and the athlete sprints back past the timing gate. A researcher was placed in line with the turning line and indicated to the researcher recording the times whether the athlete had successfully reached the turning line. Trials where the athletes did not reach the turning line were discarded, and the athlete had to repeat the trial after the required rest period. Athletes were required to turn off both the right and left leg for a total of two trials each with enough rest (≥ 2 min) between each trial. The times recorded were from the moment the athlete ran through the gates in their approach into the turn, to the moment when they passed through the gates with their run out of the turn. Time to complete the test (T_{180}) was recorded and a CODD ($CODD_{180}$) was calculated. Both values were used for statistical analyses.

90-degree cutting task

The ability to change direction at 90-degrees was assessed with a 90-degree cutting task (CV = 2%). Timing gates were placed 5-m away from a turning marker indicating the turning point and another set of timing gates 5-m away from the marker at a 90-degree angle to the first set (Figure 3). The athletes were required to sprint 10-m where they passed the first timing gate followed by another 5-m sprint to where they performed a cutting manoeuvre with either left or right foot, depending on the trial, before sprinting another 5-m past the second timing gate to finish the test. Athletes were instructed to place their foot as close as possible to the turning mark, turn to the indicated side and sprint past the second timing gate in as little time possible. A total of two trials were completed for both the right and left leg with enough rest (≥ 2 min) between trials. Time taken from the first to second timing gate was recorded as the time to complete the test (T_{90}) and a CODD value was calculated ($CODD_{90}$).

45-degree cutting task

Change of direction ability through a 45-degree turn is assessed with the 45-degree cutting task (CV = 3%). Timing gates were placed 5-m away from a beacon indicating the turning point. Another set of timing gates was placed 5-m further at a 45-degree angle from the first set. Athletes were instructed to sprint as fast as possible, place their foot (left or right depending on the side being evaluated) as close as possible to the turning beacon, and finish with a maximal sprint through the final set of timing gates. Two trials of the test were completed with sufficient rest (≥ 2 min) between trials to allow for complete recovery between trials. Total time to complete the task (T_{45}) and a CODD value ($CODD_{45}$) was used for statistical analyses.

Statistical analyses

The normality of the distribution of data was confirmed using the Shapiro-Wilk test. Initially, a simple regression analysis was done between the COD tasks and each of the strength test variables to check for collinearity. Pearson’s product-moment correlation and coefficient of determination with 95% confidence intervals were used to explore relationships among variables. Pearson’s product-moment correlation analyses will suffice as there is no maturational differences in strength post peak height velocity, and when comparing strength of males and females according to lean body mass, there is little difference between genders. Results were categorised as trivial ($r < 0.1$), small ($0.1 < r < 0.3$), moderate ($0.3 < r < 0.5$), large ($0.5 < r < 0.7$), very large ($0.7 < r < 0.9$), and nearly perfect ($r > 0.9$).[26] Stepwise multiple regression was used to determine the combined effects of statistically correlated variables, to demonstrate which variables are the best predictors of COD performance. Statistical significance was set at $p \leq 0.05$. A statistician was used to assist with data analyses and interpretation of the results (Annexure J).

Results

Table 6 shows the descriptive statistics of all the performance variables used for statistical analyses.

The correlation matrix between CODP and different strength factors can be seen in table 7. All the correlation coefficients were negative which means that an increase in the various strength measures resulted in a decrease in the time of the various COD variables. Significant moderate to large correlations between F_{ISQ} and CODP were present at all angles as well as with CODD at all angles. Jump height measured during the CMJ showed the strongest relationship among the CMJ variables with CODP. Except for the relationship between RJT-relative peak force and $CODD_{90}$, all other variables of the repeated jump test showed significant moderate-to-large correlations with all CODP variables at all angles of directional change.

The strength parameters that were the best predictors of CODP at various angles are shown in table 8 and were obtained from the stepwise multiple regression. The best predictors for both $CODD_{180}$ and T_{180} were F/BM_{RJT} and H_{RJT}. During the T_{90} the best predictor variables were M_{CMJ} and H_{RJT}, while during $CODD_{90}$ M_{CMJ} was the best predictor variable. The best predictor variables differed between the $CODD_{45}$ and T_{45} where $CODD_{45}$ was best predicted by F/BM_{ISQ}, F_{CMJ}, and F/BM_{RJT}, while T_{45} could be explained by M_{CMJ}, F/BM_{RJT}, and H_{RJT}.

Table 6. Descriptive statistics of all performance variables.

	Mean	SD
F/BM_{ISQ} (N/kg)	41.53	8.00
F_{CMJ} (N)	1837.31	427.51
F/BM_{CMJ} (N/kg)	25.02	3.43
H_{CMJ} (cm)	34.84	8.95
RSI_{CMJ} (au)	0.47	0.14
M_{CMJ} (au)	190.58	43.64
H_{RJT} (cm)	30.53	7.98
F/BM_{RJT} (N/kg)	56.84	8.42
RSI_{RJT} (au)	1.32	0.38
$CODD_{180}$ (s)	1.94	0.14
T_{180} (s)	3.26	0.24
$CODD_{90}$ (s)	0.94	0.20
T_{90} (s)	2.26	0.28
$CODD_{45}$ (s)	0.33	0.14
T_{45} (s)	1.65	0.23

Abbreviations: F/BM_{ISQ} – isometric squat relative peak force; F_{CMJ} – countermovement jump peak force; F/BM_{CMJ} – countermovement jump relative peak force; H_{CMJ} – countermovement jump-jump height; RSI_{CMJ} – countermovement jump reactive strength index; M_{CMJ} – countermovement jump take-off momentum; H_{RJT} – repeated jump test jump height; F/BM_{RJT} – repeated jump test relative peak force; RSI_{RJT} – repeated jump test reactive strength index; $CODD_{180}$ - 180-degree change of direction deficit; T_{180} – 180-degree completion time; $CODD_{90}$ – 90-degree change of direction deficit; T_{90} – 90-degree completion time; $CODD_{45}$ – 45-degree change of direction deficit; T_{45} – 45-degree completion time; CI – confidence interval; SD – standard deviation.

Table 7. Correlation matrix between all strength variables and all COD tasks

		F/BM_{ISQ}	F_{CMJ}	F/BM_{CMJ}	H_{CMJ}	RSI_{CMJ}	M_{CMJ}	H_{RJT}	F/BM_{RJT}	RSI_{RJT}
$CODD_{180}$	Pearson's r (95%CI)	-0.42 (-0.14 to -0.64)	-0.24 (0.06 to -0.50)	-0.43 (-0.16 to -0.64)	**-0.57** (-0.33 to -0.74)	**-0.52** (-0.26 to -0.70)	-0.34 (-0.06 to -0.58)	**-0.57** (-0.33 to -0.74)	-0.48 (-0.21 to -0.68)	**-0.59** (-0.36 to -0.76)
	p-value	0.004	0.113	0.003	< .001	< .001	0.021	< .001	< .001	< .001
T_{180}	Pearson's r (95%CI)	-0.43 (-0.16 to -0.64)	-0.26 (0.03 to -0.52)	-0.48 (-0.22 to -0.68)	**-0.66** (-0.46 to -0.80)	**-0.58** (-0.35 to -0.75)	-0.40 (-0.11 to -0.62)	**-0.60** (-0.38 to -0.76)	**-0.50** (-0.24 to -0.69)	**-0.63** (-0.41 to -0.78)
	p-value	0.003	0.082	< .001	< .001	< .001	0.007	< .001	< .001	< .001
$CODD_{90}$	Pearson's r (95%CI)	-0.40 (-0.12 to -0.62)	-0.31 (-0.02 to -0.56)	-0.20 (0.10 to -0.46)	-0.37 (-0.08 to -0.60)	-0.31 (-0.01 to -0.55)	-0.42 (-0.15 to -0.64)	-0.34 (-0.06 to -0.58)	-0.25 (-0.05 to -0.50)	-0.37 (-0.08 to -0.59)
	p-value	0.007	0.036	0.193	0.013	0.042	0.004	0.021	0.104	0.014
T_{90}	Pearson's r (95%CI)	-0.45 (-0.18 to -0.66)	-0.33 (-0.05 to -0.57)	-0.35 (-0.06 to -0.58)	**-0.55** (-0.31 to -0.73)	-0.47 (-0.20 to -0.67)	-0.48 (-0.21 to -0.68)	-0.49 (-0.23 to -0.69)	-0.37 (0.01 to -0.09)	**-0.51** (-0.26 to -0.70)
	p-value	0.002	0.025	0.020	< .001	0.001	< .001	< .001	0.012	< .001
$CODD_{45}$	Pearson's r (95%CI)	-0.64 (-0.43 to -0.79)	**-0.51** (-0.25 to -0.70)	**-0.51** (-0.25 to -0.70)	**-0.54** (-0.30 to -0.72)	**-0.58** (-0.35 to -0.75)	**-0.53** (-0.28 to -0.71)	**-0.57** (-0.33 to -0.74)	-0.47 (-0.21 to -0.67)	**-0.60** (-0.37 to -0.76)
	p-value	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001
T_{45}	Pearson's r (95%CI)	-0.59 (-0.36 to -0.76)	-0.44 (-0.17 to -0.65)	**-0.56** (-0.31 to -0.73)	**-0.68** (-0.49 to -0.81)	**-0.66** (-0.45 to -0.80)	**-0.53** (-0.28 to -0.71)	**-0.64** (-0.43 to -0.79)	**-0.53** (-0.28 to -0.71)	**-0.67** (-0.47 to -0.81)
	p-value	< .001	0.002	< .001	< .001	< .001	< .001	< .001	< .001	< .001

Abbreviations: F/BM_{ISQ} – isometric squat relative peak force; F_{CMJ} – countermovement jump peak force; F/BM_{CMJ} – countermovement jump relative peak force; H_{CMJ} – countermovement jump-jump height; RSI_{CMJ} – countermovement jump reactive strength index; M_{CMJ} – countermovement jump take-off momentum; H_{RJT} – repeated jump test jump height; F/BM_{RJT} – repeated jump test relative peak force; RSI_{RJT} – repeated jump test reactive strength index; $CODD_{180}$ - 180-degree change of direction deficit; T_{180} – 180-degree completion time; $CODD_{90}$ – 90-degree change of direction deficit; T_{90} – 90-degree completion time; $CODD_{45}$ – 45-degree change of direction deficit; T_{45} – 45-degree completion time. Bolded values represent moderate to large correlations.

Table 8. Stepwise multiple regression analyses results.

COD task	F-value	R^2-adjusted (95% CI)	Bests predictors (test used)	p-value	Parameter of estimate
T_{180}	15.99	0.405	F/BM_{RJT}	0.032	-0.00823
		(0.199 to 0.611)	H_{RJT}	0.001	-0.01427
$CODD_{180}$	13.05	0.354	F/BM_{RJT}	0.045	-0.00463
		(0.145 to 0.563)	H_{RJT}	0.002	-0.00767
T_{90}	10.34	0.298	M_{CMJ}	0.022	-0.00209
		(0.090 to 0.506)	H_{RJT}	0.015	-0.01218
$CODD_{90}$	9.38	0.160	M_{CMJ}	0.004	-0.00194
		(-0.027 to 0.347)			
T_{45}	18.42	0.543	M_{CMJ}	0.005	-0.00177
		(0.364 to 0.722)	F/BM_{RJT}	0.008	-0.00869
			H_{RJT}	0.006	-0.01044
$CODD_{45}$	14.32	0.476	F/BM_{ISQ}	0.017	-0.00660
		(0.284 to 0.668)	F_{CMJ}	0.048	-0.00009
			F/BM_{RJT}	0.021	-0.00506

Abbreviations: F/BM_{ISQ} – isometric squat relative peak force; F_{CMJ} – countermovement jump peak force; M_{CMJ} – countermovement jump take-off momentum; H_{RJT} – repeated jump test jump height; F/BM_{RJT} – repeated jump test relative peak force; $CODD_{180}$ – 180-degree change of direction deficit; T_{180} – 180-degree completion time; $CODD_{90}$ – 90-degree change of direction deficit; T_{90} – 90-degree completion time; $CODD_{45}$ – 45-degree change of direction deficit; T_{45} – 45-degree completion time.

Discussion

The aim of this study was to investigate the relationship between COD performance during 45-, 90-, and 180-degree cutting tasks and lower body isometric, ballistic, and plyometric strength. Ballistic strength was significantly correlated with CODP and was an important predictor during the 90-degree cutting task. Plyometric strength was significantly correlated with all COD tasks and was the best predictor of CODP at 180- and 45- degrees. A surprising finding was that isometric squat strength is significantly correlated with all COD tasks but was not a good predictor in stepwise analysis. This is likely because isometric strength underpins ballistic and plyometric performance, but it seems that the ability to apply force fast rather than the absolute amount of force that can be applied is a better predictor of performance.

Pearsons correlations

Relative peak force measured during the isometric squat showed significant moderate to large correlations with CODP at all angles as well as CODD at all angles. This is in line with the findings in the literature review of consistent moderate to very large correlations were seen between maximal strength measures and CODP.[25,28,31,35-36] These studies have in common the fact that all of them used COD tasks that require multiple directional changes which are longer in duration and less specific than the single COD tasks used in this study. This provides rationale that force measures relative to body mass is a good method to compare a measure of force output with CODP as there were significant moderate to very large relationships regardless of the COD test used in the protocol.

Jump height measured during the CMJ showed the strongest relationship among the CMJ variables with CODP. This is in line with previous research where, as demonstrated in chapter 2, several studies found significant moderate to very large relationships between CMJ jump height and various COD tests.[31,33-34,38-39,43,45,47,49,82] Michailidis et al.[44] contradicted these findings by non-significant trivial to small relationships between CMJ and 505 COD test as well as the arrowhead test in youth soccer players. The study population for this particular study was very young (9-16 years), which could influence the results. The balance of the combined evidence of the present study and other studies suggests that ballistic strength is related to CODP.

Except for the relationship between F/BM_{RJT} and $CODD_{90}$, all other variables of the repeated jump test showed significant moderate-to-large correlations with all CODP variables at all angles of directional change. During a cutting task the athlete is required decelerate and accelerate running into and out of the turn respectively, movements that require high levels of force production in a short period of time.[13] These significant moderate to very large relationships between plyometric strength and CODP using various COD tests support the relationships present in the literature review of this study.[18,29,41,44-45,50-53] Reactive strength, as represented by the repeated jump test is thus highly related to fast CODP.

Stepwise multiple regression

The best predictors of T_{180} (R^2-adjusted = 0.405) were F/BM_{RJT} and H_{RJT}. Similarly, the best predictors of $CODD_{180}$ (R^2-adjusted = 0.354) were F/BM_{RJT} and H_{RJT}. These results indicate that high levels of plyometric strength are important for performance in 180-degree COD tasks. The best predictors of T_{90} (R^2-adjusted = 0.298) were M_{CMJ} and H_{RJT}. The best predictor of $CODD_{90}$ (R^2-adjusted = 0.160) was M_{CMJ}. This suggests that ballistic strength is the most important physical quality of 90-degree cut performance. The best predictors of T_{45} (R^2-adjusted = 0.543) were M_{CMJ}, F/BM_{RJT}, and H_{RJT}. The best predictors of $CODD_{45}$ (R^2-adjusted = 0.476) were F/BM_{ISQ}, F_{CMJ}, and F/BM_{RJT}. These results suggest that speed through a 45-degree cutting task is predicted by ballistic and plyometric qualities and not maximum isometric strength. This makes sense because these qualities are also associated with acceleration and maximal speed.[83] However, the change of direction skill, as determined by CODD, at speed seems to depend on the ability to exert high amounts of force. Best predictor variables during $CODD_{45}$ was relative peak force production during the isometric squat and repeated jump test, and absolute peak force output during the CMJ.

Strong correlations between isometric strength and CODP at all angles indicate that strength and conditioning coaches who want to improve their athletes' ability to change direction as fast as possible need to ensure that their athletes are able to produce high levels of force. Once adequately strong the practitioners need to improve the ability to produce force as quickly as possible in their athletes and can make use of plyometric movements to achieve this.

Limitations

The field-based testing was conducted on a grass rugby field and hockey astroturf for rugby and hockey players respectively. Ideally, both groups perform field-based testing on a standardized surface. Another limitation was the time of day that the field-based testing was conducted. Due to the nature of the testing battery, the athletes first completed the lab-based tests and then relocated to the fields to complete the field-based tests, which by then occurred between 10 am and 12 pm. The athletes prepared for the day from their respective homes and thus we were unable to control the nutrition at the start of the day.

Conclusion

The aim of this study was to investigate the relationship between COD performance during 45-, 90-, and 180-degree cutting tasks and lower body isometric, ballistic, and plyometric strength. Practitioners who want to improve their athlete's ability to change direction as fast as possible should firstly ensure the athletes are adequately strong as strength was associated with performance in all tests. Once adequately strong, the aim should be to improve the ability to produce force as quickly as possible through the use of plyometric movements.

Chapter 4: Conclusion

Summary

Change of direction (COD) is a component of agility that requires the ability to decelerate, change movement direction, and accelerate again where no immediate reaction to a stimulus is required.[1-4] Change of direction performance (CODP) is simply put the overall task that involves a maximum effort run into a turn, directional change and a maximal effort run out of the turn, and can be assessed as the total time to complete a change of direction task. Isometric strength represents the maximum possible amount of force that an athlete can produce without a change in joint angles. Lower body ballistic movements are classified as jumping events with a slow stretch-shortening cycle (contraction time > 250ms), while lower body plyometric are jumping events with a fast stretch-shortening cycle (contraction time < 250ms).[22] Prior to this study, the physical performance capabilities that underpin different CODP, had yet to be clearly defined. Sport scientists could find it useful to understand the relationship between CODP and isometric-, ballistic-, and plyometric strength to better be able to train the specific strength qualities required during a change of direction task. Thus, the aim of this study was to investigate the relationship between COD performance during 45-, 90-, and 180-degree cutting tasks and lower body isometric, ballistic, and plyometric strength.

A review of the literature revealed that ballistic- and plyometric strength qualities relate strongly to CODP, while there were mixed results regarding the relationship between maximal strength and CODP. There is limited evidence in the literature to show that training programs designed to improve maximal-, ballistic-, and plyometric strength affects CODP, suggesting that effective strength training interventions for improving CODP still requires investigation. While it is clear that isometric-, ballistic-, and plyometric strength may be related to COD performance, there isn’t enough information to clearly understand if different strength capacities are more beneficial for different COD tasks. There is limited research on strength factors associated with single COD tasks with less than 180-degree angles. Using COD tasks with single directional changes allows the sport scientists to isolate the physical quality they are trying to assess. Thus, it would be useful to determine the effect of different types of lower body strength factors on COD tasks that require single directional changes at different angles.

The experimental study found moderate to very large relationships between all strength factors and all variables of the different COD tasks except for $CODD_{90}$ which only had non-meaningful relationships with strength variables. Relative peak force during the isometric squat showed significant moderate to very large relationships with all CODP as well as CODD variables. Jump height measured during the CMJ showed the strongest relationship among the CMJ variables with CODP. Except for the relationship between F/BM_{RJT} and $CODD_{90}$, all other variables of the repeated jump test showed significant moderate-to-large correlations with all CODP variables at all angles of directional change.

The best predictors of T_{180} were F/BM_{RJT} and H_{RJT}. Similarly, the best predictors of $CODD_{180}$ were F/BM_{RJT} and H_{RJT}. Predictor variables during 90-degree COD tasks were M_{CMJ} and H_{RJT} for T_{90} and M_{CMJ} for $CODD_{90}$. The time to complete the 45-degree change of direction task was best predicted by M_{CMJ}, RF/BM_{RJT}, and H_{RJT}. The best predictors of $CODD_{45}$, however, were F/BM_{ISO}, F_{CMJ}, and F/BM_{RJT}. These predictor variables are due to the nature of the forceful decelerations and accelerations required during a short period of time to be successful at changing direction as fast as possible.

Limitations

Athletes used during this study included only hockey and rugby players, both from sports that predominantly requires less than 90-degree cutting tasks in their sport. This could have influenced the outcome of this study as they are better conditioned for cutting tasks of less than 90-degrees. A broader range of sports would have been more desirable. Another limitation is the sample size. Only 45 athletes participated in this study, but a bigger sample size could have given us a more realistic idea of what is seen in practice. Field-based testing was conducted on a grass rugby field by the rugby players and a hockey astroturf by the hockey players. Ideally, both groups perform field-based testing on a standardized surface in an indoor facility to avoid the influence of weather conditions to manipulate the results. The athletes prepared for the day from their respective homes and thus we were unable to control the nutrition at the start of the day. During the literature review, some studies that could have added value were excluded due to being written in different languages and also not being available at the time of the search. The literature suggests that technique is an important part of COD ability, but during this study technique was not examined as part of the predictors of CODP.

Implications of findings

The aim of this study was to investigate the relationship between COD performance during 45-, 90-, and 180-degree cutting tasks and lower body isometric, ballistic, and plyometric strength. Main findings show that there are significant moderate to very large relationships between isometric, ballistic, and plyometric strength and CODP during 180-, 90-, and 45-degree cutting tasks. This study also showed that plyometric strength during the repeated jump test is the best predictor variable of CODP during all COD tasks. During a COD task, the athlete needs to produce enough force to overcome inertia and subsequently manipulate momentum to efficiently decelerate, change movement direction, and reaccelerate in the new direction. It is also desirable for this production of force to happen in as short a period of time as possible to minimize ground contact time and thus improve COD time. Results from this study also indicate that the difference between different angles of directional change is not enough to justify using different strength training methods to improve CODP at different angles of directional change. Strength and conditioning coaches who need to improve their athletes' COD ability should start by assessing the sport and identifying the most frequently used angles of directional changes. From there the practitioners can assess the COD ability of the athlete using a single COD task at an angle that is in line with the demands of the sport as well as their linear sprinting ability. Strength and conditioning coaches should then proceed to assess maximal, ballistic, and plyometric strength. The next step would be to identify weaknesses among these tests and focus on the qualities associated with the test first. The practitioner must ensure that the athletes have adequate strength to produce enough force to accelerate out of the turn. If strength is adequate, the practitioner should focus on improving the athletes' ability to produce force as quickly as possible with the use of plyometric movements. Lastly, the athlete should actively train COD movements that occur most frequently in the sport as COD is a technical skill activity that is underpinned by lower limb strength qualities.[1,19]

Previous literature provides insight into associations of different strength factors with CODP. These associations have been used in literature to assess the effect of training interventions on CODP. This literature is, however, inconsistent and more research is needed on the exact training interventions required to improve CODP. The current study provides insight as to which strength factors are associated with, and best predicts CODP. Future research is needed on the exact training interventions to effectively improve plyometric strength during the 10-to-5 repeated jump test and subsequently improve the athlete's ability to rapidly change movement direction as high velocities.

References

1. Brughelli M, Cronin J, Levin G, Chaouachi A. Understanding change of direction ability in sport. Sports Med. 2008; 38(12):1045-63.

2. Thomas C, Dos'Santos T, Comfort P, Jones PA. Relationships between unilateral muscle strength qualities and change of direction in adolescent team-sport athletes. Sports. 2018; 6(3):83.

3. Jones P, Bampouras T, Marrin K. An investigation into the physical determinants of change of direction speed. J Sports Med Phys Fitness. 2009; 49(1):97-104.

4. Dos' Santos T, Thomas C, Jones PA, Comfort P. Mechanical determinants of faster change of direction speed performance in male athletes. J Strength Cond Res. 2017; 31(3):696-705.

5. Cuthbert M, Thomas C, Dos'Santos T, Jones PA. Application of change of direction deficit to evaluate cutting ability. J Strength Cond Res. 2019; 33(8):2138-44.

6. Dos' Santos T, Thomas C, Jones PA, Comfort P. Assessing asymmetries in change of direction speed performance: Application of change of direction deficit. J Strength Cond Res. 2019; 33(11):2953-61.

7. Nimphius S, Callaghan SJ, Spiteri T, Lockie RG. Change of direction deficit: A more isolated measure of change of direction performance than total 505 time. J Strength Cond Res. 2016; 30(11):3024-32.

8. Nimphius S, Geib G, Spiteri T, Carlisle D. Change of direction" deficit measurement in division i american football players. J Aust Strength Cond. 2013; 21(S2):115-7.

9. Lockie RG, Farzad J, Orjalo AJ, Giuliano DV, Moreno MR, Wright GA. A methodological report: Adapting the 505 change-of-direction speed test specific to american football. J Strength Cond Res. 2017; 31(2):539-47.

10. Spiteri T, Newton RU, Binetti M, Hart NH, Sheppard JM, Nimphius S. Mechanical determinants of faster change of direction and agility performance in female basketball athletes. J Strength Cond Res. 2015; 29(8):2205-14.

11. Rouissi M, Chtara M, Owen A, Chaalali A, Chaouachi A, Gabbett T, et al. Effect of leg dominance on change of direction ability amongst young elite soccer players. Journal of Sports Sciences. 2016; 34(6):542-8.

12. Watts D. A brief review on the role of maximal strength in change of direction speed. J Aust Strength Cond. 2015; 23(2):100-8.

13. Dos'Santos T, Thomas C, Comfort P, Jones PA. The effect of angle and velocity on change of direction biomechanics: An angle-velocity trade-off. Sports Med. 2018; 48(10):2235-53.

14. Brady CJ, Harrison AJ, Comyns TM. A review of the reliability of biomechanical variables produced during the isometric mid-thigh pull and isometric squat and the reporting of normative data. Sports Biomech. 2020; 19(1):1-25.

15. Jaric S. Force-velocity relationship of muscles performing multi-joint maximum performance tasks. Int J Sports Med. 2015; 36(09):699-704.

16. Cormie P, McGuigan MR, Newton RU. Adaptations in athletic performance after ballistic power versus strength training. Med Sci Sports Exerc. 2010; 42(8):1582-98.

17. Shah S. Plyometric exercises. Int J Health Sci Res. 2012; 2(1):115-26.

18. Young WB, James R, Montgomery I. Is muscle power related to running speed with changes of direction? J Sports Med Phys Fitness. 2002; 42(3):282-8.

19. Sheppard JM, Young WB. Agility literature review: Classifications, training and testing. J Sports Sci. 2006; 24(9):919-32.

20. Hader K, Palazzi D, Buchheit M. Change of direction speed in soccer: How much braking is enough? Kinesiology. 2015; 47(1.):67-74.

21. Jones PA, Thomas C, Dos'Santos T, McMahon JJ, Graham-Smith P. The role of eccentric strength in 180° turns in female soccer players. Sports. 2017; 5(2):42.

22. Schmidtbleicher D. Training for power events. Strength and power in sport. 1992; 1:381-95.

23. Chaabene H, Prieske O, Negra Y, Granacher U. Change of direction speed: Toward a strength training approach with accentuated eccentric muscle actions. Sports Med. 2018; 48(8):1773-9.

24. Asadi A, Arazi H, Young WB, Saez de Villarreal E. The effects of plyometric training on change-of-direction ability: A meta-analysis. International Journal of Sports Physiology & Performance. 2016; 11(5):563-73.

25. Nimphius S, McGuigan MR, Newton RU. Changes in muscle architecture and performance during a competitive season in female softball players. J Strength Cond Res. 2012; 26(10):2655-66.

26. Hopkins WG, Marshall SW, Batterham AM, Hanin J. Progressive statistics for studies in sports medicine and exercise science. Med Sci Sports Exerc. 2009; 41(1):3-13.

27. Duthie GM, Thomas EJ, Bahnisch J, Thornton HR, Ball K. Using small-sided games in field hockey: Can they be used to reach match intensity? J Strength Cond Res. 2019;

28. Bourgeois Ii FA, McGuigan MR, Winchester JB, Brem RW, Wyatt FB. The relationship between strength and change of direction performance in college football players. J Aust Strength Cond. 2014; 22(5):132-4.

29. Delaney JA, Scott TJ, Ballard DA, Duthie GM, Hickmans JA, Lockie RG, et al. Contributing factors to change-of-direction ability in professional rugby league players. J Strength Cond Res. 2015; 29(10):2688-96.

30. Markovic G. Poor relationship between strength and power qualities and agility performance. J Sports Med Phys Fitness. 2007; 47(3):276-83.

31. Nimphius S, McGuigan MR, Newton RU. Relationship between strength, power, speed, and change of direction performance of female softball players. J Strength Cond Res. 2010; 24(4):885-95.

32. Papla M, Krzysztofik M, Wojdala G, Roczniok R, Oslizlo M, Golas A. Relationships between linear sprint, lower-body power output and change of direction performance in elite soccer players. Int J Environ Res Public Health. 2020; 17(17)

33. Ranisavljev I, Matić M, Janković N. The relationship between maximum strength, the vertical jump, acceleration and change of direction performance. Facta Univ Ser Phys Educ Sport. 2019; 17(3):591-9.

34. Scanlan AT, Wen N, Pyne DB, Stojanović E, Milanović Z, Conte D, et al. Power-related determinants of modified agility t-test performance in male adolescent basketball players. J Strength Cond Res. 2019; 00(00):1-7.

35. Spiteri T, Nimphius S, Hart NH, Specos C, Sheppard JM, Newton RU. Contribution of strength characteristics to change of direction and agility performance in female basketball athletes. J Strength Cond Res. 2014; 28(9):2415-23.

36. Swinton PA, Lloyd R, Keogh JWL, Agouris I, Stewart AD. Regression models of sprint, vertical jump, and change of direction performance. J Strength Cond Res. 2014; 28(7):1839-48.

37. Wang R, Hoffman JR, Tanigawa S, Miramonti AA, La Monica MB, Beyer KS, et al. Isometric mid-thigh pull correlates with strength, sprint, and agility performance in collegiate rugby union players. J Strength Cond Res. 2016; 30(11):3051-6.

38. Alemdaroğlu U. The relationship between muscle strength, anaerobic performance, agility, sprint ability and vertical jump performance in professional basketball players. J Hum Kinet. 2012; 31:149-58.

39. Barnes JL, Schilling BK, Falvo MJ, Weiss LW, Creasy AK, Fry AC. Relationship of jumping and agility performance in female volleyball athletes. J Strength Cond Res. 2007; 21(4):1192-6.

40. Collins KS, Coburn JW, Galpin AJ, Lockie RG. Relationships and reliability between a drive block test and traditional football performance tests in high school offensive line players. J Strength Cond Res. 2018; 32(12):3423-32.

41. Falch HN, Rædergård HG, van den Tillaar R. Association of strength and plyometric exercises with change of direction performances. PloS one. 2020; 15(9):e0238580.

42. Los Arcos A, Aramendi JF, Emparanza JI, Castagna C, Yanci J, Lezáun A, et al. Assessing change of direction ability in a spanish elite soccer academy. J Hum Kinet. 2020; 72(1):229-39.

43. Meylan C, McMaster T, Cronin J, Mohammad NI, Rogers C, Deklerk M. Single-leg lateral, horizontal, and vertical jump assessment: Reliability, interrelationships, and ability to predict sprint and change-of-direction performance. J Strength Cond Res. 2009; 23(4):1140-7.

44. Michailidis Y, Savvakis C, Pirounakis V, Mikikis D, Margonis K, Metaxas T. Association between jump asymmetry and reduced performance in the change of direction tests of youth soccer players. J Phys Educ Sport. 2020; 20(3):1362-8.

45. Negra Y, Chaabene H, Hammami M, Amara S, Sammoud S, Mkaouer B, et al. Agility in young athletes: Is it a different ability from speed and power? J Strength Cond Res. 2017; 31(3):727-35.

46. Rouissi M, Chtara M, Owen A, Burnett A, Chamari K. Change of direction ability in young elite soccer players: Determining factors vary with angle variation. J Sports Med Phys Fitness. 2017; 57(42924):960-8.

47. Schultz FA, Cavazzoni P, Carnevale RV, Abad CCC, Kobal R, Pereira LA, et al. Speed and power predictors of change of direction ability in elite snow athletes. J Hum Sport Exerc. 2015; 10(4):847-56.

48. Sisic N, Jelicic M, Pehar M, Spasic M, Sekulic D. Agility performance in high-level junior basketball players: The predictive value of anthropometrics and power qualities. J Sports Med Phys Fitness. 2016; 56(7-8):884-93.

49. Yanci J, Arcos AL, Castillo D, Cámara J. Sprinting, change of direction ability and horizontal jump performance in youth runners according to gender. J Hum Kinet. 2017; 60(1):199-207.

50. Yanci J, Los Arcos A, Mendiguchia J, Brughelli M. Relationships between sprinting, agility, one- and two-leg vertical and horizontal jump in soccer players. Kinesiology. 2014; 46(2):194-201.

51. Hirose N, Nakahori C. Age differences in change-of-direction performance and its subelements in female football players. Int J Sports Physiol Perform. 2015; 10(4):440-5.

52. Maloney SJ, Richards J, Nixon DGD, Harvey LJ, Fletcher IM. Do stiffness and asymmetries predict change of direction performance? J Sports Sci. 2017; 35(6):547-56.

53. Miki N, Kaoru U, Megumi T, Toshiyuki N, Yasuo S, Junya S, et al. Relationships of single-leg rebound jump performances with sprint and change of direction performances between legs with functional ankle instabilities. J Aust Strength Cond. 2014; 22(5):91-4.

54. Appleby BB, Cormack SJ, Newton RU. Unilateral and bilateral lower-body resistance training does not transfer equally to sprint and change of direction performance. J Strength Cond Res. 2020; 34(1):54-64.

55. Banyard HG, Tufano JJ, Weakley JJS, Wu S, Jukic I, Nosaka K. Superior changes in jump, sprint, and change-of-direction performance but not maximal strength following 6 weeks of velocity-based training compared with 1-repetition-maximum percentage-based training. Int J Sports Physiol Perform. 2020; 16(2):1-11.

56. Davies MJ, Drury B, Ramirez-Campillo R, Chaabane H, Moran J. Effect of plyometric training and biological maturation on jump and change of direction ability in female youth. J Strength Cond Res. 2019; 00(00):1-8.

57. De Hoyo M, Gonzalo-Skok O, SaĐUdo B, Carrascal C, Plaza-Armas JR, Camacho-Candil F, et al. Comparative effects of in-season full-back squat, resisted sprint training, and plyometric training on explosive performance in u-19 elite soccer players. J Strength Cond Res. 2016; 30(2):368-77.

58. de Hoyo M, Sañudo B, Carrasco L, Domínguez-Cobo S, Mateo-Cortes J, Cadenas-Sánchez MM, et al. Effects of traditional versus horizontal inertial flywheel power training on common sport-related tasks. J Hum Kinet. 2015; 47(1):155-67.

59. Freitas-Junior CG, Fortes LS, Santos TM, Batista GR, Gantois P, Paes PP. Effects of different training strategies with a weight vest on countermovement vertical jump and change-of-direction ability in male volleyball athletes. J Sports Med Phys Fitness. 2020; 61(3):343-9.

60. Gonzalo-Skok O, Tous-Fajardo J, Suarez-Arrones L, Arjol-Serrano JL, Casajús JA, Mendez-Villanueva A. Single-leg power output and between-limbs imbalances in team-sport players: Unilateral versus bilateral combined resistance training. Int J Sports Physiol Perform. 2017; 12(1):106-14.

61. Hale D, Kollock R, Pace J, Sanders G. Vertical jump and agility performance improve after an 8-week conditioning program in youth female volleyball athletes. J Phys Educ Sport. 2019; 19(1):765-71.

62. Hammami M, Gaamouri N, Aloui G, Shephard RJ, Chelly MS. Effects of a complex strength-training program on athletic performance of junior female handball players. Int J Sports Physiol Perform. 2019; 14(2):163-9.

63. Hammami M, Negra Y, Shephard RJ, Chelly M-S. Effects of leg contrast strength training on sprint, agility and repeated change of direction performance in male soccer players. J Sports Med Phys Fitness. 2017; 57(11):1424-31.

64. Jlid MC, Racil G, Coquart J, Paillard T, Bisciotti GN, Chamari K. Multidirectional plyometric training: Very efficient way to improve vertical jump performance, change of direction performance and dynamic postural control in young soccer players. Frontiers in physiology. 2019; 10:1462.

65. Loturco I, Kobal R, Kitamura K, Cal Abad CC, Faust B, Almeida L, et al. Mixed training methods: Effects of combining resisted sprints or plyometrics with optimum power loads on sprint and agility performance in professional soccer players. Frontiers in physiology. 2017; 8:1034.

66. Makhlouf I, Castagna C, Manzi V, Laurencelle L, Behm DG, Chaouachi A. Effect of sequencing strength and endurance training in young male soccer players. J Strength Cond Res. 2016; 30(3):841-50.

67. Ramirez-Campillo R, Sanchez-Sanchez J, Gonzalo-Skok O, Rodríguez-Fernandez A, Carretero M, Nakamura FY. Specific changes in young soccer player's fitness after traditional bilateral vs. Unilateral combined strength and plyometric training. Frontiers in physiology. 2018; 9:265.

68. Ramirez-Campillo R, Alvarez C, García-Pinillos F, Sanchez-Sanchez J, Yanci J, Castillo D, et al. Optimal reactive strength index: Is it an accurate variable to optimize plyometric training effects on measures of physical fitness in young soccer players? J Strength Cond Res. 2018; 32(4):885-93.

69. Ramirez-Campillo R, García-Pinillos F, García-Ramos A, Yanci J, Gentil P, Chaabene H, et al. Effects of different plyometric training frequencies on components of physical fitness in amateur female soccer players. Frontiers in physiology. 2018; 9:934.

70. Sanchez-Sanchez J, Gonzalo-Skok O, Carretero M, Pineda A, Ramirez-Campillo R, Yuzo Nakamura F. Effects of concurrent eccentric overload and high-intensity interval training on team sports players' performance. Kinesiology. 2019; 51(1):119-26.

71. Shalfawi SAI, Haugen T, Jakobsen TA, Enoksen E, Tønnessen E. The effect of combined resisted agility and repeated sprint training vs. Strength training on female elite soccer players. J Strength Cond Res. 2013; 27(11):2966-72.

72. Singh J, Appleby BB, Lavender AP. Effect of plyometric training on speed and change of direction ability in elite field hockey players. Sports. 2018; 6(4):144.

73. Yanci J, Castillo D, Iturricastillo A, Ayarra R, Nakamura FY. Effects of two different volume-equated weekly distributed short-term plyometric training programs on futsal players' physical performance. J Strength Cond Res. 2017; 31(7):1787-94.

74. Yanci J, Los Arcos A, Camara J, Castillo D, García A, Castagna C. Effects of horizontal plyometric training volume on soccer players’ performance. Res Sports Med. 2016; 24(4):308-19.

75. Zghal F, Colson SS, Blain G, Behm DG, Granacher U, Chaouachi A. Combined resistance and plyometric training is more effective than plyometric training alone for improving physical fitness of pubertal soccer players. Frontiers in physiology. 2019; 10:1026. doi:10.3389/fphys.2019.01026

76. Demura S, Miyaguchi K, Shin S, Uchida Y. Effectiveness of the 1rm estimation method based on isometric squat using a back-dynamometer. The Journal of Strength & Conditioning Research. 2010; 24(10):2742-8.

77. Rhea MR, Kenn JG, Peterson MD, Massey D, Simão R, Marin PJ, et al. Joint-angle specific strength adaptations influence improvements in power in highly trained athletes. Hum Mov. 2016; 17(1):43-9.

78. Flanagan EP, Comyns TM. The use of contact time and the reactive strength index to optimize fast stretch-shortening cycle training. Strength Cond J. 2008; 30(5):32-8.

79. McMahon JJ, Suchomel TJ, Lake JP, Comfort P. Relationship between reactive strength index variants in rugby league players. J Strength Cond Res. 2021; 35(1):280-5.

80. Comyns T, Flangan E, Harper D, Fleming S, Fitzgerald E. Interday reliability and usefulness of reactive strength index derived from the ten to five repeated jump test. J Sports Sci. 2017; 35(Sup2):S80.

81. Harper D, Hobbs S, Moore J, editors. The ten to five repeated jump test: A new test for evaluation 188 of lower body reactive strength. British Association of Sports and Exercises Sciences 189 Student Conference; 2011.

82. Bourgeois Ii FA, Gamble P, Gill ND, McGuigan MR. The relationship between multidirectional jumping and performance in change of direction tasks. J Strength Cond Res. 2018; 32(3):690-9.

83. Cronin JB, Hansen KT. Strength and power predictors of sports speed. J Strength Cond Res. 2005; 19(2):349-57.

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

ANNEXURES

Annexure A: Research ethics committee approval certificate (2021)

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Faculty of Health Sciences

Institution: The Research Ethics Committee, Faculty Health Sciences, University of Pretoria complies with ICH-GCP guidelines and has US Federal wide Assurance.

- FWA 00002567, Approved dd 22 May 2002 and Expires 03/20/2022.
- IORG #: IORG0001762 OMB No. 0990-0279 Approved for use through February 28, 2022 and Expires: 03/04/2023.

Faculty of Health Sciences **Research Ethics Committee**

11 November 2021

Approval Certificate
Amendment

Dear Mr C van Zyl

Ethics Reference No.: 600/2020
Title: Strength factors associated with performance in change of direction tasks at different angles.

The **Amendment** as supported by documents received between 2021-10-22 and 2021-11-10 for your research, was approved by the Faculty of Health Sciences Research Ethics Committee on 2021-11-10 as resolved by its quorate meeting.

Please note the following about your ethics approval:

- Please remember to use your protocol number (600/2020) on any documents or correspondence with the Research Ethics Committee regarding your research.
- Please note that the Research Ethics Committee may ask further questions, seek additional information, require further modification, monitor the conduct of your research, or suspend or withdraw ethics approval.

Ethics approval is subject to the following:

- The ethics approval is conditional on the research being conducted as stipulated by the details of all documents submitted to the Committee. In the event that a further need arises to change who the investigators are, the methods or any other aspect, such changes must be submitted as an Amendment for approval by the Committee.

We wish you the best with your research.

Yours sincerely

On behalf of the FHS REC, Dr R Sommers
MBChB, MMed (Int), MPharmMed, PhD
Deputy Chairperson *of the Faculty of Health Sciences Research Ethics Committee, University of Pretoria*

The Faculty of Health Sciences Research Ethics Committee complies with the SA National Act 61 of 2003 as it pertains to health research and the United States Code of Federal Regulations Title 45 and 46. This committee abides by the ethical norms and principles for research, established by the Declaration of Helsinki, the South African Medical Research Council Guidelines as well as the Guidelines for Ethical Research: Principles Structures and Processes, Second Edition 2015 (Department of Health).

Research Ethics Committee
Room 4-60, Level 4, Tswelopele Building
University of Pretoria, Private Bag x323
Gezina 0031, South Africa
Tel +27 (0)12 356 3084
Email: deepeka.behari@up.ac.za
www.up.ac.za

Fakulteit Gesondheidswetenskappe
Lefapha la Disaense tša Maphelo

Annexure B: Research ethics committee approval certificate (2020)

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Faculty of Health Sciences

Institution: The Research Ethics Committee, Faculty Health Sciences, University of Pretoria complies with ICH-GCP guidelines and has US Federal wide Assurance.
- FWA 00002567, Approved dd 22 May 2002 and Expires 03/20/2022.
- IORG #: IORG0001762 OMB No. 0990-0279 Approved for use through February 28, 2022 and Expires: 03/04/2023.

23 October 2020

Approval Certificate
New Application

Ethics Reference No.: 600/2020
Title: Strength factors associated with change-of-direction performance using the 505 test and a 90-degree cutting task

Dear Mr C van Zyl

The **New Application** as supported by documents received between 2020-09-23 and 2020-10-21 for your research, was approved by the Faculty of Health Sciences Research Ethics Committee on 2020-10-21 as resolved by its quorate meeting.

Please note the following about your ethics approval:
- Ethics Approval is valid for 1 year and needs to be renewed annually by 2021-10-23.
- Please remember to use your protocol number (600/2020) on any documents or correspondence with the Research Ethics Committee regarding your research.
- Please note that the Research Ethics Committee may ask further questions, seek additional information, require further modification, monitor the conduct of your research, or suspend or withdraw ethics approval.

Ethics approval is subject to the following:
- The ethics approval is conditional on the research being conducted as stipulated by the details of all documents submitted to the Committee. In the event that a further need arises to change who the investigators are, the methods or any other aspect, such changes must be submitted as an Amendment for approval by the Committee.

We wish you the best with your research.

Yours sincerely

Dr R Sommers
MBChB MMed (Int) MPharmMed PhD
Deputy Chairperson of the Faculty of Health Sciences Research Ethics Committee, University of Pretoria

The Faculty of Health Sciences Research Ethics Committee complies with the SA National Act 61 of 2003 as it pertains to health research and the United States Code of Federal Regulations Title 45 and 46. This committee abides by the ethical norms and principles for research, established by the Declaration of Helsinki, the South African Medical Research Council Guidelines as well as the Guidelines for Ethical Research: Principles Structures and Processes, Second Edition 2015 (Department of Health)

Research Ethics Committee
Room 4-60, Level 4, Tswelopele Building
University of Pretoria, Private Bag x323
Gezina 0031, South Africa
Tel +27 (0)12 356 3084
Email: deepeka.behari@up.ac.za
www.up.ac.za

Fakulteit Gesondheidswetenskappe
Lefapha la Disaense tša Maphelo

Annexure C: Proposal 83/2016

The Research Ethics Committee, Faculty Health Sciences, University of Pretoria complies with ICH-GCP guidelines and has US Federal wide Assurance.

- FWA 00002567, Approved dd 22 May 2002 and Expires 20 Oct 2016.
- IRB 0000 2235 IORG0001762 Approved dd 22/04/2014 and Expires 22/04/2017.

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Faculty of Health Sciences Research Ethics Committee

21/04/2016

Approval Certificate
New Application

Ethics Reference No.: 83/2016

Title: Student athlete health, well-being and sports performance: A prospective study over 5 years

Dear Martin Schwellnus

The **New Application** as supported by documents specified in your cover letter dated 5/04/2016 for your research received on the 18/04/2016, was approved by the Faculty of Health Sciences Research Ethics Committee on its quorate meeting of 20/04/2016.

Please note the following about your ethics approval:

- Ethics Approval is valid for 5 years
- Please remember to use your protocol number (**83/2016**) on any documents or correspondence with the Research Ethics Committee regarding your research.
- Please note that the Research Ethics Committee may ask further questions, seek additional information, require further modification, or monitor the conduct of your research.

Ethics approval is subject to the following:

- The ethics approval is conditional on the receipt of 6 monthly written Progress Reports, and
- The ethics approval is conditional on the research being conducted as stipulated by the details of all documents submitted to the Committee. In the event that a further need arises to change who the investigators are, the methods or any other aspect, such changes must be submitted as an Amendment for approval by the Committee.

Additional Conditions:

- Approved, on condition that no blood may be sampled for genetic testing at present, until further consideration by a further submission to the REC.

We wish you the best with your research.

Yours sincerely

*** Kindly collect your original signed approval certificate from our offices, Faculty of Health Sciences, Research Ethics Committee, H W Snyman South Building, Room 2.33 / 2.34.*

Professor Werdie (CW) Van Staden
MBChB MMed(Psych) MD FCPsych FTCL UPLM
Chairperson: Faculty of Health Sciences Research Ethics Committee

The Faculty of Health Sciences Research Ethics Committee complies with the SA National Act 61 of 2003 as it pertains to health research and the United States Code of Federal Regulations Title 45 and 46. This committee abides by the ethical norms and principles for research, established by the Declaration of Helsinki, the South African Medical Research Council Guidelines as well as the Guidelines for Ethical Research: Principles Structures and Processes 2004 (Department of Health).

☎ 012 354 1677 0866516047 deepeka.behari@up.ac.za http://www.up.ac.za/healthethics
Private Bag X323, Arcadia, 0007 - 31 Bophelo Road, HW Snyman South Building, Level 2, Room 2.33, Gezina, Pretoria

Annexure D: Declaration of Helsinki

Special Communication

World Medical Association Declaration of Helsinki Ethical Principles for Medical Research Involving Human Subjects

World Medical Association

Adopted by the 18th WMA General Assembly, Helsinki, Finland, June 1964, and amended by the:
29th WMA General Assembly, Tokyo, Japan, October 1975
35th WMA General Assembly, Venice, Italy, October 1983
41st WMA General Assembly, Hong Kong, September 1989
48th WMA General Assembly, Somerset West, Republic of South Africa, October 1996
52nd WMA General Assembly, Edinburgh, Scotland, October 2000
53rd WMA General Assembly, Washington, DC, USA, October 2002 (Note of Clarification added)
55th WMA General Assembly, Tokyo, Japan, October 2004 (Note of Clarification added)
59th WMA General Assembly, Seoul, Republic of Korea, October 2008
64th WMA General Assembly, Fortaleza, Brazil, October 2013

Preamble

1. The World Medical Association (WMA) has developed the Declaration of Helsinki as a statement of ethical principles for medical research involving human subjects, including research on identifiable human material and data.

   The Declaration is intended to be read as a whole and each of its constituent paragraphs should be applied with consideration of all other relevant paragraphs.

2. Consistent with the mandate of the WMA, the Declaration is addressed primarily to physicians. The WMA encourages others who are involved in medical research involving human subjects to adopt these principles.

General Principles

3. The Declaration of Geneva of the WMA binds the physician with the words, "The health of my patient will be my first consideration," and the International Code of Medical Ethics declares that, "A physician shall act in the patient's best interest when providing medical care."

4. It is the duty of the physician to promote and safeguard the health, well-being and rights of patients, including those who are involved in medical research. The physician's knowledge and conscience are dedicated to the fulfilment of this duty.

5. Medical progress is based on research that ultimately must include studies involving human subjects.

6. The primary purpose of medical research involving human subjects is to understand the causes, development and effects of diseases and improve preventive, diagnostic and therapeutic interventions (methods, procedures and treatments). Even the best proven interventions must be evaluated continually through research for their safety, effectiveness, efficiency, accessibility and quality.

7. Medical research is subject to ethical standards that promote and ensure respect for all human subjects and protect their health and rights.

8. While the primary purpose of medical research is to generate new knowledge, this goal can never take precedence over the rights and interests of individual research subjects.

9. It is the duty of physicians who are involved in medical research to protect the life, health, dignity, integrity, right to self-determination, privacy, and confidentiality of personal information of research subjects. The responsibility for the protection of research subjects must always rest with the physician or other health care professionals and never with the research subjects, even though they have given consent.

10. Physicians must consider the ethical, legal and regulatory norms and standards for research involving human subjects in their own countries as well as applicable international norms and standards. No national or international ethical, legal or regulatory requirement should reduce or eliminate any of the protections for research subjects set forth in this Declaration.

11. Medical research should be conducted in a manner that minimises possible harm to the environment.

12. Medical research involving human subjects must be conducted only by individuals with the appropriate ethics and scientific education, training and qualifications. Research on patients or healthy volunteers requires the supervision of a competent and appropriately qualified physician or other health care professional.

13. Groups that are underrepresented in medical research should be provided appropriate access to participation in research.

14. Physicians who combine medical research with medical care should involve their patients in research only to the extent that this is justified by its potential preventive, diagnostic or therapeutic value and if the physician has good reason to believe that participation in the research study will not adversely affect the health of the patients who serve as research subjects.

15. Appropriate compensation and treatment for subjects who are harmed as a result of participating in research must be ensured.

Risks, Burdens and Benefits

16. In medical practice and in medical research, most interventions involve risks and burdens.

    Medical research involving human subjects may only be conducted if the importance of the objective outweighs the risks and burdens to the research subjects.

17. All medical research involving human subjects must be preceded by careful assessment of predictable risks and burdens to the individuals and groups involved in the research in comparison with foreseeable benefits to them and to other individuals or groups affected by the condition under investigation.

    Measures to minimise the risks must be implemented. The risks must be continuously monitored, assessed and documented by the researcher.

18. Physicians may not be involved in a research study involving human subjects unless they are confident that the risks have been adequately assessed and can be satisfactorily managed.

    When the risks are found to outweigh the potential benefits or when there is conclusive proof of definitive outcomes, physicians must assess whether to continue, modify or immediately stop the study.

Vulnerable Groups and Individuals

19. Some groups and individuals are particularly vulnerable and may have an increased likelihood of being wronged or of incurring additional harm.

    All vulnerable groups and individuals should receive specifically considered protection.

20. Medical research with a vulnerable group is only justified if the research is responsive to the health needs or priorities of this group and the research cannot be carried out in a non-vulnerable group. In addition, this group should stand to benefit from the knowledge, practices or interventions that result from the research.

Scientific Requirements and Research Protocols

21. Medical research involving human subjects must conform to generally accepted scientific principles, be based on a thorough knowledge of the scientific literature, other relevant sources of information, and adequate laboratory and, as appropriate, animal experimentation. The welfare of animals used for research must be respected.

22. The design and performance of each research study involving human subjects must be clearly described and justified in a research protocol.

    The protocol should contain a statement of the ethical considerations involved and should indicate how the principles in this Declaration have been addressed. The protocol should include information regarding funding, sponsors, institutional affiliations, potential conflicts of interest, incentives for subjects and information regarding provisions for treating and/or compensating subjects who are harmed as a consequence of participation in the research study.

    In clinical trials, the protocol must also describe appropriate arrangements for post-trial provisions.

Research Ethics Committees

23. The research protocol must be submitted for consideration, comment, guidance and approval to the concerned research ethics committee before the study begins. This committee must be transparent in its functioning, must be independent of the researcher, the sponsor and any other undue influence and must be duly qualified. It must take into consideration the laws and regulations of the country or countries in which the research is to be performed as well as applicable international norms and standards but these must not be allowed to reduce or eliminate any of the protections for research subjects set forth in this Declaration.

    The committee must have the right to monitor ongoing studies. The researcher must provide monitoring information to the committee, especially information about any serious adverse events. No amendment to the protocol may be made without consideration and approval by the committee. After the end of the study, the researchers must submit a final report to the committee containing a summary of the study's findings and conclusions.

Privacy and Confidentiality

24. Every precaution must be taken to protect the privacy of research subjects and the confidentiality of their personal information.

Informed Consent

25. Participation by individuals capable of giving informed consent as subjects in medical research must be voluntary. Although it

may be appropriate to consult family members or community leaders, no individual capable of giving informed consent may be enrolled in a research study unless he or she freely agrees.

26. In medical research involving human subjects capable of giving informed consent, each potential subject must be adequately informed of the aims, methods, sources of funding, any possible conflicts of interest, institutional affiliations of the researcher, the anticipated benefits and potential risks of the study and the discomfort it may entail, post-study provisions and any other relevant aspects of the study. The potential subject must be informed of the right to refuse to participate in the study or to withdraw consent to participate at any time without reprisal. Special attention should be given to the specific information needs of individual potential subjects as well as to the methods used to deliver the information.

    After ensuring that the potential subject has understood the information, the physician or another appropriately qualified individual must then seek the potential subject's freely-given informed consent, preferably in writing. If the consent cannot be expressed in writing, the non-written consent must be formally documented and witnessed.

    All medical research subjects should be given the option of being informed about the general outcome and results of the study.

27. When seeking informed consent for participation in a research study the physician must be particularly cautious if the potential subject is in a dependent relationship with the physician or may consent under duress. In such situations the informed consent must be sought by an appropriately qualified individual who is completely independent of this relationship.

28. For a potential research subject who is incapable of giving informed consent, the physician must seek informed consent from the legally authorised representative. These individuals must not be included in a research study that has no likelihood of benefit for them unless it is intended to promote the health of the group represented by the potential subject, the research cannot instead be performed with persons capable of providing informed consent, and the research entails only minimal risk and minimal burden.

29. When a potential research subject who is deemed incapable of giving informed consent is able to give assent to decisions about participation in research, the physician must seek that assent in addition to the consent of the legally authorised representative. The potential subject's dissent should be respected.

30. Research involving subjects who are physically or mentally incapable of giving consent, for example, unconscious patients, may be done only if the physical or mental condition that prevents giving informed consent is a necessary characteristic of the research group. In such circumstances the physician must seek informed consent from the legally authorised representative. If no such representative is available and if the research cannot be delayed, the study may proceed without informed consent provided that the specific reasons for involving subjects with a condition that renders them unable to give informed consent have been stated in the research protocol and the study has been approved by a research ethics committee. Consent to remain in the research must be obtained as soon as possible from the subject or a legally authorised representative.

31. The physician must fully inform the patient which aspects of their care are related to the research. The refusal of a patient to participate in a study or the patient's decision to withdraw from the study must never adversely affect the patient-physician relationship.

32. For medical research using identifiable human material or data, such as research on material or data contained in biobanks or similar repositories, physicians must seek informed consent for its collection, storage and/or reuse. There may be exceptional situations where consent would be impossible or impracticable to obtain for such research. In such situations the research may be done only after consideration and approval of a research ethics committee.

Use of Placebo

33. The benefits, risks, burdens and effectiveness of a new intervention must be tested against those of the best proven intervention(s), except in the following circumstances:

    Where no proven intervention exists, the use of placebo, or no intervention, is acceptable; or

    Where for compelling and scientifically sound methodological reasons the use of any intervention less effective than the best proven one, the use of placebo, or no intervention is necessary to determine the efficacy or safety of an intervention

    and the patients who receive any intervention less effective than the best proven one, placebo, or no intervention will not be subject to additional risks of serious or irreversible harm as a result of not receiving the best proven intervention.

    Extreme care must be taken to avoid abuse of this option.

Post-Trial Provisions

34. In advance of a clinical trial, sponsors, researchers and host country governments should make provisions for post-trial access for all participants who still need an intervention identified as beneficial in the trial. This information must also be disclosed to participants during the informed consent process.

Research Registration and Publication and Dissemination of Results

35. Every research study involving human subjects must be registered in a publicly accessible database before recruitment of the first subject.

36. Researchers, authors, sponsors, editors and publishers all have ethical obligations with regard to the publication and dissemination of the results of research. Researchers have a duty to make publicly available the results of their research on human subjects and are accountable for the completeness and accuracy of their reports. All parties should adhere to accepted guidelines for ethical reporting. Negative and inconclusive as well as positive results must be published or otherwise made publicly available. Sources of funding, institutional affiliations and conflicts of interest must be declared in the publication. Reports of research not in accordance with the principles of this Declaration should not be accepted for publication.

Unproven Interventions in Clinical Practice

37. In the treatment of an individual patient, where proven interventions do not exist or other known interventions have been ineffective, the physician, after seeking expert advice, with informed consent from the patient or a legally authorised representative, may use an unproven intervention if in the physician's judgement it offers hope of saving life, re-establishing health or alleviating suffering. This intervention should subsequently be made the object of research, designed to evaluate its safety and efficacy. In all cases, new information must be recorded and, where appropriate, made publicly available.

ARTICLE INFORMATION

Corresponding Author: World Medical Association, 13, ch. du Levant, CIB - Bâtiment A, 01210 Ferney-Voltaire, France; wma@wma.net.

Published Online: October 19, 2013. doi:10.1001/jama.2013.281053.

Online-Only Content: Audio podcast is available at www.jama.com.

Annexure E: Adult consent

Student athlete health, well-being and sports performance: A prospective study over 5 years

ADULT PARTICIPANT INFORMATION AND INFORMED CONSENT DOCUMENT

Introduction

You are invited to volunteer to participate in a research study. This leaflet is to help you to decide if you would like to participate. Before you agree to take part in this study you should fully understand what is involved. If you have any questions that are not fully explained in this leaflet, do not hesitate to contact the investigators.

The nature and purpose of this study

Researchers from the Institute for Sport, Exercise Medicine and Lifestyle Research at the University of Pretoria will conduct a study entitled "Student athlete health, well-being and sports performance: A prospective study over 5 years". The study aims to identify factors that affect student athlete health (Illness, injury), well-being (psychological status), academic performance and sports performance.

Explanation of procedures to be followed

Your participation in this research study is entirely voluntary. A number of the components described below are part of the routine assessment and monitoring procedures for your sport. Should you agree to participate, you would be asked to give consent to participate in the following components of the study:

- Functional movement and musculoskeletal screening assessment. This is a series of tests to assess your movement quality, mobility and strength. The assessment will be completed 1 – 2 times per year by a sport scientist.
- Sport-specific physiological testing. Sport scientists conduct a series of tests to assess physiological components that are relevant to your sport, which may include body composition, flexibility, explosive power, muscular strength, muscular endurance, speed, agility, aerobic or anaerobic capacity, or sportsspecific performance related tests. You will receive the results of all tests, which may be used by your coaches to inform your training program. The testing will take place 1 – 4 times per year.

- Biomechanical analysis: Motion capture techniques, are used to analyse athletic movement qualities and sport specific technique. These assessments take place 1 – 4 times per year.
- Complete an annual online medical history questionnaire. You will be provided with a unique user account to an online athlete management system where the form will be completed, and this will take less than 1 hour in total.
- Undergo a standard physical examination, based on recommended procedures for athletes by international bodies such as IOC and FIFA. The examination will be completed annually by a sports physician at the University of Pretoria sports campus.
- Donate a blood sample (15ml or 3 teaspoons). This sample will be used for the extraction and analysis of genetic material (DNA). The DNA will only be used for scientific research purposes relating to determination of the risk of injuries and illness. Samples will be destroyed on completion of the study.
- Complete an illness/injury monitoring questionnaire. Once a week, you will complete a short online questionnaire where you will be asked a few questions about any injuries or illnesses that have occurred. The questionnaire will take no more than 15 minutes to complete.
- Physical load and training response monitoring through a daily questionnaire that will take no more than 5 minutes to complete.
- Complete the Nutritional and Dietary Supplement Assessment monitoring questionnaire once a year
- Provide the research team with access to your academic records.
- Provide the research team access to your medical records, if you were treated by a medical or allied health professional. This includes medical records that are captured by medical staff on the electronic online athlete management system that is used at the Sport, Exercise Medicine and Lifestyle Institute (SEMLI).

All questionnaires may be completed on your personal computer, a computer at the university, a tablet, or a smart phone. If using a tablet or smart phone, it can be completed off-line and uploaded when wi-fi connection is available.

Potential risks of this study

- The completion of questionnaires or a physical examination is not associated with any risk. Questionnaires and other clinical data (paper and electronic) will be kept confidential and secure, and will not be made available to any party other than the research team without the consent of the individual participant.
- Musculoskeletal, physiological and biomechanical assessment requires physical tasks that involve some risk of musculoskeletal injury. However, all tasks will involve similar loads and movements that you engage in during regular training and competition. These types of tests are standard procedure in elite sport. You will be allowed to complete a full warm-up routine of your choice before beginning the testing. All reasonable precautions

to reduce the risk of injury will be taken, and all testing will be conducted by appropriately qualified staff.

- All medical conditions will be treated as usual by your doctor or physiotherapist, and training will continue as usual under your strength and conditioning trainer. Medical records will be captured and stored on a fully secure electronic online athlete management system that is used at the Sport, Exercise Medicine and Lifestyle Institute (SEMLI).
- The potential risks during the 5 ml (1 teaspoon) blood collection include: infection, delayed healing, haematoma, physical pain, mental discomfort and injury to a nerve or a vessel. These risks are small and will be minimized by the use of trained phlebotomists, use of sterile techniques and the use of disposable, single-use materials.
- Genetic information: To make sure that your specific genetic information is kept secure and confidential, the following procedures will be adopted: 1) all the blood samples will be labelled on collection using a numerical coding system that is linked to player details on a master list that will be placed in a sealed envelope, 2) this sealed master list will then be kept in a secure facility and in a separate location, 3) only the principle investigator and senior co-investigators will have access to this master list, 4) the master list will only be opened if a sample needs to be destroyed, should a participant request this. All data will be analysed anonymously and DNA samples will be destroyed on completion of the study. Your personal genetic information will not be made known to you, your teammates, team medical staff, coaches, or management. The information will be kept secure, anonymous and will only be used for research purposes. Because this area of research is still in the exploratory phase, we will not be able to provide individual feedback with regards to the results and implications of genetic testing.
- You may withdraw from this study at any time without question.

Potential benefits of this study

You will be provided with the results of your musculoskeletal, physiological and biomechanical assessments, which you may share with your coach or strength and conditioning trainer. The research questions that will be addressed by this study have been identified to have a direct impact on improving health, well-being and performance in student athletes. The anticipated benefits of this study are that the results will further our understanding of the possible cause/s of medical conditions and injuries in athletes.

Ethical Approval

This Protocol was submitted to the Faculty of Health Sciences Research Ethics Committee, University of Pretoria (telephone number 012 356 3084) and written approval has been granted by that committee. The study has been structured in accordance with the Declaration of Helsinki (last update: October 2013), which deals with the recommendations guiding doctors in biomedical research involving human/subjects. A copy of the Declaration may be obtained from the investigator should you wish to review it.

Confidentiality

All records obtained whilst in this study will be regarded as confidential. Once we have analysed the information no one will be able to identify you. Results will be published or presented in such a fashion that participants remain unidentifiable.

Contact

Please feel free to contact a member of the research team or the University of Pretoria Health Sciences Research Office should you have any questions related to the study. You can contact the principal investigator on the following number: (012) 420 1804.

Faculty of Health Sciences - Research Ethics Committee

Tswelopele Building, Level 4, Rooms 4-59 and 4-Faculty of Health Sciences, Dr Savage Road, Gezina,

Pretoria

Tel: (012) 356 3084 or (012) 356 3085

Fax: (086) 651 6047

Email: manda.smith@up.ac.za / deepeka.behari@up.ac.za / fhsethics@up.ac.za

University of Pretoria Research Ethics approval number: 83/2016

Consent to participate in this study

I confirm that I have received, read (or had read to me) and understood the above written information regarding the nature, process, risks, discomforts and benefits of the study. I have been given opportunity to submit questions and am satisfied that they have been answered satisfactorily. I agree that research data provided by me or with my permission during the study may be included in a thesis, presented at conferences and published in journals on the condition that neither my name nor any other identifying information is used. I understand that if I do not participate it will not alter my management in any way. I understand that I may withdraw from this study at any time without further question.

I hereby consent to participate in the following components of the study as described in the participant information that I received

Please initial under either "yes" or "no" for each component:

	Yes	No
Functional movement and musculoskeletal screening		
Sport-specific testing		
Biomechanical assessment		
Annual Online Medical History Questionnaire		
Annual Medical Screening Examination		
Weekly illness/injury monitoring questionnaire		
Access to my medical records		
Physical load and daily training response monitoring		
Nutritional and Dietary Supplement Assessment		
Genetic component of this study		
Access to my academic records		

Please complete the participant and witness columns:

	Participant (Athlete)	Witness	Investigator
Name Please Print			To be completed by research team
Signature			To be completed by research team
Date			To be completed by research team

Annexure F: Youth assent form

Strength factors associated with performance in change of direction tasks at different angles

YOUTH ATHLETE ASSENT DOCUMENT

Dear student athlete:

As an athlete at the Jeppe High School for Boys you have been selected to take part in a student project study. The information gathered during this study will be used by the coaches and support staff to optimize training programs. We wish to know if we may use your information in our research study.

The following tests will be conducted for data gathering purposes:

- Sport-specific physiological testing. Sport scientists conduct a series of tests to assess physiological components that are relevant to your sport, which may include body composition, flexibility, explosive power, muscular strength, muscular endurance, speed, agility, aerobic or anaerobic capacity, or sports-specific performance related tests. You will receive the results of all tests, which may be used by your coaches to inform your training program.
- Biomechanical analysis: Motion capture techniques, are used to analyse athletic movement qualities and sport specific technique.

None of the above-mentioned tests will harm you in any way.

If you do not want to or are not comfortable with any of the above tasks asked of you, you may refuse to do them at any stage and if you want to, still participate further in the study. If you do not want to take part any more you may decide at any time during the study, not to carry on. No-one will force you to carry on. No-one will be cross or upset with you if you don't want to, your training will continue as normal.

If you sign below, it will mean that you have read this paper, and that you would like to be in this study.

Please complete the athlete and parent/guardian/witness columns:

	Athlete	Parent / Guardian / Other Witness	Investigator
Name Please Print			To be completed by research team
Signature			To be completed by research team
Date			To be completed by research team

Annexure G: Parent consent form

Strength factors associated with performance in change of direction tasks at different angles

PARENT OR GUARDIAN INFORMATION & INFORMED CONSENT DOCUMENT

INTRODUCTION

Your child has been invited to volunteer for a research study. This information leaflet will help you to decide if you want your child to participate. Before you agree to take part on behalf of your child you should fully understand what is involved. You should not agree unless you are completely happy about all the procedures involved. If you have any questions that this leaflet does not fully explain, please do not hesitate to contact the investigators.

THE NATURE AND PURPOSE OF THIS STUDY

Changing direction fast and efficiently is an attribute which is of desire by many team sport athletes. This study aims determine the relationship between different measures of strength and change of direction performance. Three different strength tests will be done as well as two change of direction tests and one straight line running test. Knowledge of these factors could help sport scientists and strength and conditioning coaches better target specific physical attributes to improve the ability to change direction more efficiently. With this we would like to ask permission to collect data about your child for the purpose of this study. This study is important as the results could guide practitioners develop better athletes.

EXPLANATION OF PROCEDURES TO BE FOLLOWED

The following tests will be conducted for data gathering purposes:

Sport-specific physiological testing. Sport scientists conduct a series of tests to assess physiological components that are relevant to your sport, which may include body composition, flexibility, explosive power, muscular strength, muscular endurance, speed, agility, aerobic or anaerobic capacity, or sports-specific performance related tests. You will receive the results of all tests, which may be used by your coaches to inform your training program.

Biomechanical analysis: Motion capture techniques, are used to analyse athletic movement qualities and sport specific technique.

RISK AND DISCOMFORT INVOLVED

Sport-specific tests are designed to test the limit of athletes and thus, some of them require maximum efforts which could feel uncomfortable as well as some risk of musculoskeletal injury. These tests are, however, conducted using standard procedures and qualified personnel oversee conducting them. Your child will be allowed to complete a full warm-up routine of his/her choice before beginning testing.

Biomechanical assessment requires physical tasks that involve some risk of musculoskeletal injury. However, all tasks will involve similar loads and movements that the child engage in during regular training and competition. These types of tests are standard procedure in elite sport. He/she will be allowed to complete a full warm-up routine of his/her choice before beginning the testing.

You / your child may withdraw from this study at any time without question.

POSSIBLE BENEFITS OF THIS STUDY

The research questions that will be addressed by this study have been identified to have a direct impact on improving health, well-being and performance in student athletes. The anticipated benefits of this study are that the results will further our understanding of sport performance in athletes and this knowledge will thus be used to better enhance athletic ability.

WHAT ARE YOUR CHILD'S RIGHTS AS A PARTICIPANT?

Your child's participation in this study is entirely voluntary. You can refuse to give permission for him/her to participate or stop at any time during the study. Your withdrawal will not affect his/her normal training or treatment in any way.

HAS THE STUDY RECEIVED ETHICAL APPROVAL?

This Protocol was submitted to the Faculty of Health Sciences Research Ethics Committee, University of Pretoria (telephone number 012 356 3084) and written approval has been granted by that committee. The study has been structured in accordance with the Declaration of Helsinki (last update: October 2013), which deals with the recommendations guiding doctors in biomedical research involving human/subjects. A copy of the Declaration may be obtained from the investigator should you wish to review it.

COMPENSATION

Your child's participation is voluntary without any financial compensation.

CONFIDENTIALITY

All information that you give will be kept strictly confidential. Once we have analysed the information no one will be able to identify you. Research reports, academic presentations and articles in scientific journals will not include any information that may identify you or your child.

CONTACT

Please feel free to contact a member of the research team or the University of Pretoria Health Sciences Research Office should you have any questions related to the study. You can contact the principal investigator on the following number: (+27) 71 233 6626

Faculty of Health Sciences - Research Ethics Committee

Tswelopele Building, Level 4, Rooms 4-59 and 4-Faculty of Health Sciences, Dr Savage Road, Gezina, Pretoria

Tel: (012) 356 3084 or (012) 356 3085

Fax: (086) 651 6047

Email: manda.smith@up.ac.za / deepeka.behari@up.ac.za / fhsethics@up.ac.za

University of Pretoria Research Ethics approval number: 83/2016

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

CONSENT TO PARTICIPATE IN THIS STUDY

I confirm that I have received, read (or had read to me) and understood the above written information regarding the nature, process, risks, discomforts and benefits of the study. I have been given opportunity to submit questions and have no objections to my child's participation. I understand that there is no penalty should I wish to withdraw my child's participation in the study and withdrawal will not affect his/her academic tuition or sports participation. I am aware that the results of the study, including personal details, will be anonymously processed into research reports.

I hereby give consent for my child to participate in the following components of the study as described in the participant information leaflet that I received

Please initial under either "yes" or "no" for each component:

	Yes	No
Sport-specific testing		
Biomechanical assessment		

Please complete the participant and witness columns:

	Participant (Athlete's	**Witness**	**Investigator**
Name **Please Print**			To be completed by research team
Signature			To be completed by research team
Date			To be completed by research team

Annexure H: Permission to use SEMLI's facilities

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

SEMLI
Sport, Exercise Medicine
and Lifestyle Institute

27 May 2020

To whom it may concern:

Permission to use SEMLI's facilities, equipment and associated data

I hereby grant the following student permission to use SEMLI facilities and equipment and associated data for research purposes for their degree.

Student name:	Christo van Zyl
Student number:	15200885
Degree programme:	MSc Sports Science
Working title:	Strength factors associated with change-of-direction performance using the 505 test and a 90-degree cutting task

The project partially falls under the umbrella protocol (431/2015) entitled "Student athlete health, well-being and sports performance: A prospective study over 5 years", for which I am the principal investigator.

Prof. M Schwellnus
Director: SEMLI
Faculty of Health Sciences
University of Pretoria

Annexure I: Permission for study with TuksSport

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA
TuksSport

3rd June 2020

To Whom It May Concern:

RE: Permission for Study within TuksSport

This letter serves as confirmation that TuksSport, through my office, has been approached by the researcher requesting permission to approach our various TuksSport specific clubs for the purpose of the research stated below.

Degree: MSc Sport Science

Student: Ms. C. Van Zyl (15200885)

Faculty and Department: Faculty of Health Sciences, Department of Physiology

We hereby grant permission for the researchers to approach the TuksSport Club, as agreed upon with myself. We suggest that this drive is done through my office, so as to encourage the coaches participation and endorsement of the research. The request is that the findings of the research be provided to TuksSport and club after assessment and on completion of the research.

At TuksSport, we are encouraging the practical research application into our club systems, which aligns with the University of Pretoria's 2025 strategic vision and plan and ultimately aid and enhance our sporting performances on the field of play.

Please feel free to contact me if you have any questions.

Yours Sincerely

Mr S. Ball

DEPUTY DIRECTOR: Coaching & Performance Management

Building and Room no: TuksSport Complex
University of Pretoria
PRETORIA 0002
Republic of South Africa

Tel: (012) 420 2828
Fax: 086 636 4014

Email address: steven.ball@up.ac.za
www.up.ac.za

Annexure J: Letter of statistical support

)EPARTMENT OF STATISTICS

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA
Denkleiers • Leading Minds • Dikgopolo tša Dihlalefi

LETTER OF STATISTICAL SUPPORT

Date: 29 May 2020

This letter is to confirm that Mr C van Zyl, studying at the University of Pretoria, discussed the project with the title "Strength factors associated with change-of-direction performance using the 505 test and a 90-degree cutting task" with me.

I hereby confirm that I am aware of the project and I also undertake to assist with the statistical analysis of the data generated from the project.

The estimated sample size was determined as follows: A power analysis using G*Power version 3.1.9.2 indicated that for a multiple regression model with five predictors; a medium effect size of

0.15; $\alpha = 0.05$ and $1 - \beta = 0.80$, a total sample size of 55 will be required.

The data analysis will consist of single frequencies, cross-tables and descriptive statistics such as means and standard deviations. Inferential statistics will include correlation coefficients (Pearson's correlation coefficient or Spearman's rho) and multiple regression analysis. Apart from

measurements of isometric, ballistic and plyometric strength, age (in years) may be included in the model as a covariate, and if the number of males and females are comparable, sex could be included as an indicator variable. The possible presence of multi-collinearity between the predictors will be investigated and, if applicable, the regression model will be adjusted accordingly.

JC Jordaan

Ms JC Jordaan
Research Consultant
Internal Statistical Consultation Service
Department of Statistics
Email address: joyce.jordaan@up.ac.za