The Relationships between the Dynamic Strength Index and Performance Metrics in Professional Football Players

Tan Jian Zhi Kenny (Kenny J.Z. Tan)

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Primary Supervisor: Dr. Adam Storey

Secondary Supervisor: Dr. Marcus Lee

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Attestation of authorship

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

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Date: 1/7/2024

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Ethical approval

The Auckland University of Technology Ethics Committee (AUTEC) approved this research on 18/09/2023. Amendments to the protocol were approved on 01/11/2023. Ethics Application: 23/251

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$$DSI = PF_{dyn} / PF_{iso} \quad (1)$$

$$\int_{t_i}^{t_{to}} F_{GRF}dt - \int_{t_i}^{t_{to}} F_{BW}dt \quad (2)$$

$$\int_{t_i}^{t_{CMJ}} F_{GRF}dt - \int_{t_i}^{t_{CMJ}} F_{onset}dt \quad (3)$$

$$DSI_{NJM} = \text{CMJ Peak } NJM_{Hip,Knee,Ankle} / \text{ IMTP Peak } NJM_{Hip,Knee,Ankle} \quad (4)$$

$$DSD = PF_{dyn} \text{ in FP POP} / PF_{iso} \text{ in IBP} \quad (5)$$

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List of common abbreviations

DSI	Dynamic Strength Index	COD	Change of direction
CMJ	Countermovement Jump	CODD	Change of direction deficit
CMJ-H	Countermovement Jump Height	DSD	Dynamic Strength Deficit
SJ	Squat jump	Mod505	Modified 505 agility test
IMTP	Isometric mid-thigh pull	Tra505	Traditional 505 agility test
ISQ	Isometric squat	IAT	Illinois agility test
IBP	Isometric bench press	BBT	Ballistic bench throw
ICC	Intraclass correlation coefficient	%CV	Coefficient of variation
PF_{dyn}	Concentric peak force of a dynamic strength measure	aPF	Average peak force
PF_{iso}	Concentric peak force of an isometric strength measure	rPF	Relative peak force
D	Dominant	ND	Non-dominant

Abstract

The Dynamic Strength Index (DSI) assesses an athlete's ability to dynamically utilise their maximal strength capacity for guiding training decisions, sharing similar physical qualities with change of direction (COD) activities, such as the involvement of the slow stretch-shortening cycle in larger degrees of COD, due to the greater ground contact times involved. To date, there is only one known study directly investigating the relationship between DSI and COD. For this thesis, Chapter 2 comprises a literature review on the different methods used to calculate the DSI in the existing literature and the links between DSI and performance, while Chapter 3 reports on an empirical study investigating the possible relationships between DSI and its components with COD performance and other commonly measured performance metrics, like jump height and sprint performance. The primary findings from the literature review in Chapter 2 were that the DSI was most commonly used to assess lower body bilateral strength, using the countermovement jump (CMJ) and isometric mid-thigh pull (IMTP). These findings were used to inform the methodology used in Chapter 3, where a cross-sectional study was conducted on professional football players during their pre-season. The main findings from Chapter 3 were that the DSI was not significantly related to any of the jump height, COD and sprint performances, which makes it unsuitable as a diagnostic tool for these physical measures. CMJ height was related to both 10 m and 30 m sprint performances, as well as performance in the longer COD test, the Illinois Agility Test (IAT). Thus, CMJ height can be considered by coaches as a monitoring tool for the performance of professional football players. When assessing COD ability, there could be value in including both a shorter COD test like the mod505 and a longer COD test like the IAT as they are not interchangeable measures and thus offer a more comprehensive overview.

Chapter 1: Introduction and rationale

1.1 Background

Within professional soccer, gym-based assessments like the isometric mid-thigh pull (IMTP) and countermovement jump (CMJ) are assessment tools employed by strength and conditioning coaches to monitor players' physical conditions over the duration of a playing season due to their relationships with sprinting and COD performance (Haugen et al., 2012; Comfort et al., 2014; Köklü et al., 2015; Mason et al., 2021). The Dynamic Strength Index (DSI) is a ratio formed between the concentric peak force of a maximal dynamic movement like CMJ with the peak force of a maximal voluntary isometric contraction like the IMTP (Sheppard et al., 2011). The DSI indicates the degree that an athlete is able to dynamically utilize their maximal strength capabilities, which can possibly help inform if the athlete requires more maximal or dynamic strength training (Young et al., 2014).

Change of direction (COD) is an important aspect of football, constituting 12-16% of total player load, with deceleration movements having the highest mechanical load per meter among football movements (Dalen et al., 2016). Rapid horizontal deceleration involves peak levels of muscle activation exceeding that of maximal voluntary isometric contractions (Hewit et al., 2011; McBurnie et al., 2022). Since the lower body biomechanical demands during a COD task peak at the sharpest angles (i.e., 180°), the traditional 505 (tra505) and modified 505 (mod505) agility tests are suitable measures to track sport performance and injury risk in players; via identification of strength imbalances and deficits (Dos Santos et al., 2018). In addition, both isometric and dynamic strength have been found to be significantly correlated to 180° COD ability in the tra505, indicating the potential relevance of the DSI as a diagnostic tool (Spiteri et al., 2014). To date, only one study (Pleša et al., 2023b) has directly investigated the relationship between DSI and COD ability in male basketball players, finding no relationships between DSI and tra505 performance during the pre-season and significant moderate positive correlations during the in-season.

1.1 Purpose statement

The primary goal of this thesis was to determine if there was a relationship between the DSI and its components with COD and sprinting ability. The investigation was conducted on professional football players for the following reasons:

1) To date, no known study has investigated the relationship between the DSI and COD performance in the mod505.
2) To date, no known study has investigated the relationship between the DSI and COD performance in this particular demographic of professional football players.

Previous research conducted on a separate demographic has found some moderate positive relationships between DSI and COD time in the tra505 during the in-season and not during the pre-season. The findings of this study could be used to extend the previous findings, using a separate 180° COD test in the form of the mod505, as well as a longer COD test in the form of the Illinois Agility Test (IAT).

This thesis attempted to investigate if there was a potential link between the DSI and COD performance, to establish the potential usefulness of the DSI as a diagnostic tool in monitoring COD and sprinting ability.

1.2 Research aims and hypotheses

The primary aim of this thesis was to 1) investigate the relationships between DSI and its components with CMJ height, running sprints, COD and deceleration time in professional football players. The findings of this thesis will have practical implications on whether the DSI is a suitable diagnostic tool to monitor COD ability as well as the other common performance measures like sprinting and jump height in football. In light of the findings of Pleša et al. (2023b), we hypothesized that for 1), there will be no significant relationship between DSI and COD time.

In addition, COD in football has a unique element where COD performance tends to be better on the dominant leg (Rouissi et al., 2016; Clemente et al., 2022). The usage of the mod505 test also offers an opportunity to investigate the relationships between supplementary COD metrics: the change of direction deficit (CODD) and sub-phase analysis using additional timing splits (Nimphius et al., 2013; Ryan et al., 2021). Thus, the secondary research aims were to investigate: 2) possible differences between the dominant and non-dominant legs during the mod505 test and 3) the relationships between the different supplementary COD measures in the mod505; the CODD and sub-phase analysis. We hypothesized that for 2), COD performance will be better on the dominant leg and for 3), there will be significant relationships between CODD and some of the sub-phases of the mod505.

1.3 Structure of the thesis

Chapter 2 of the thesis is a review of the current literature pertaining to the DSI; the various methods used to calculate it as well as its links to different sport performance measures.

Chapter 3 is an experimental cross-sectional study where professional football players performed a series of gym-based and field-based assessments during the pre-season phase of their competitive season.

Chapter 4 is the final chapter comprising the summary and conclusion of the thesis. Practical recommendations, limitations of the present study and potential areas for future research are presented.

Chapter 2: Literature review of the Dynamic Strength Index: methods and links to performance

2.1 Preface

The purpose of this chapter is to identify and review the literature relevant to the Dynamic Strength Index (DSI). The chapter will be split into two main parts (2.4 and 2.5). The first part (2.4) will focus on the available studies on the DSI in the literature and discuss the methodology used, normative DSI values, as well as alternative calculation methods. The second part (2.5) will discuss the link between DSI and different performance measures, the effect training has on DSI as well as the possible link between DSI and change of direction (COD).

2.2 Introduction

Resistance training plays a pivotal role in enhancing sport performance and reducing injury risk of athletes via the development of muscular strength (Suchomel et al., 2016). In addition, the physical force-time characteristics of a muscle, such as rate of force development and external mechanical power, are typical adaptations seen following structured resistance training (Suchomel et al., 2016). While mechanically defined as work done per unit of time, 'power' is commonly expressed as a generic neuromuscular or athlete performance trait within strength and conditioning circles, linked to 'explosiveness' and the ability to generate force quickly (Turner et al., 2020). A large body of literature has shown that strength and power measures developed through resistance training are positively correlated to various key physical performance measures in sports, such as sprinting and jumping and are thus able to differentiate between athletes of different expertise levels (McGuigan et al., 2012; Suchomel et al., 2016).

With limited time and recovery resources, training economy is an important consideration for athletes. One area of contention is the extent of transference that strength training has to sport performance. McGuigan et al. (2012) discussed how improvements in strength and power may not directly transfer to improvements in sport-specific motor performance measures. The degree of transference may be affected by factors such as the type of sport, positional demands and the stage of the athlete's career. A 'lag time' has also been proposed as a period where athletes learn to translate improvements in their physical capabilities into sport-specific improvements. Aşçi & Açikada (2007) found that for athletes with similar upper body strength levels and different sport backgrounds, there were no differences in strength-speed characteristics, suggesting that in this scenario, regular resistance training played a larger role than long-term specific sport adaptations for development of upper body power.

Training economy considerations are further amplified via how strength and ballistic training differ in their effect on the force-time characteristic adaptations of muscles, with ballistic training emphasizing the first 0.3s of movements and maximal strength training emphasizing the peak height of the force-time curve (Turner et al., 2021). Considering that most sporting movements take place within the first 0.3s, ballistic training would typically appear to be more sport-specific, though the development of an athlete's foundational strength is also essential up to a certain point (Turner et al., 2020). As such, the conversation has now shifted towards selecting the training modality that will be the most appropriate for athletes at any one point of time. For instance, Suchomel et al. (2016) proposed the usage of relative back squat strength as a lower body barometer to determine the type of resistance training an athlete should focus on. Accordingly, a ≥ 2x bodyweight back squat is classified as the point where additional maximal strength gains would give diminishing sport-specific returns, at which the focus should shift towards power training (Suchomel et al. 2016).

The Dynamic Strength Index (DSI), or Dynamic Strength Deficit as it was coined by Sheppard et al. (2011), is a ratio formed between the concentric peak force of a maximal dynamic movement with the peak force of a maximal voluntary isometric contraction. The DSI metric indicates the degree that an athlete can dynamically utilize their maximal strength capabilities (Young et al., 2014). The DSI assessment protocol was initially described by Young (1995), where a value of ≤0.5 suggested that the athlete would require more speed-strength training while ≥0.5 would suggest the need for more maximal strength training. Sheppard et al. (2011) suggested different thresholds, where a low DSI value (≤0.6) indicates a poor ability and a need to focus on ballistic training, while a high DSI value (≥0.8) indicates a need to focus more on maximal strength training. As such, the DSI is a tool that could theoretically help to identify if athletes require more ballistic or maximal strength training and inform training decisions to suit athletes' individual training needs.

The purpose of this literature review is to outline the work that has been done on the DSI thus far as well as its link to different performance measures.

2.3 Literature review search methods

An electronic database search was conducted using the search engines PubMed, Taylor & Francis Online, Google Scholar and SPORTDiscus to identify potential articles. The following search terms were used: ballistic, dynamic strength index (DSI), isometric mid-thigh pull (IMTP), isometric squat (ISQ), squat jump (SJ) and countermovement jump (CMJ). Further literature was obtained from electronic 'related articles' searches and by manually screening the reference lists of the included studies. The specific inclusion criteria included 1) lower-body and/or upper-body focused DSI measurements, 2) a detailed explanation of the procedures and methods, 3) written in English, and 4) research studies solely conducted with human participants. Despite being introduced as a testing protocol initially by Young (1995), the concept was not formally tested in the scientific literature until 2011 when Sheppard et al. published the paper "An evaluation of a strength qualities assessment method for the lower body" which conceptualised the DSI. As such, papers from 2011 onwards were included in the review, with brief references to Young (1995).

2.4 Different DSI assessments, methodology and mean values

During its introduction by Young (1995), this form of assessment was initially coined 'maximum dynamic strength index', where the peak force in a SJ or CMJ was expressed as a percentage of the peak force in an ISQ. This assessment was tested by Sheppard et al. (2011) using the SJ and IMTP, formally conceptualising the DSI as a ratio formed between the concentric peak force of a dynamic strength measure (PF_{dyn}), with the concentric peak force of an isometric strength measure (PF_{iso}) (1):

$$DSI = PF_{dyn} / PF_{iso} \quad (1)$$

Since then, studies have utilized the DSI in various contexts using different dynamic and isometric strength measures (Table 1).

Table 1

Demographics, measures and DSI values of studies in chronological order

Reference	Population	Sport	Dynamic strength measure	Isometric strength measure	Type of DSI	DSI (Mean ± SD)
Sheppard et al. (2011)	15M, 3F	Rowing, gymnastics, sprint cycling, and volleyball	SJ (KA: 110°, light wooden bar on shoulders, ‘jump as high as possible’)	IMTP (KA: 130°, HA:155-160°)	Bilateral lower body	0.70 ± 0.10
Young et al. (2014)	24M	Field hockey, gymnastics, water polo, volleyball	Ballistic bench throw (BBT) with 45% of bench press 1RM	Isometric bench press (IBP) (60°, 90°, 120°, 150° of elbow flexion)	Bilateral upper body	Not reported.
Thomas et al. (2015b)	19M	Cricket, judo, rugby, weightlifting, boxing, and football	SJ (KA: approximately 135°, hands on hips, jump for maximal height)	IMTP (self-selected depth)	Bilateral lower body	0.78 ± 0.19
Young et al. (2015)	24M	Field hockey, gymnastics, water polo, volleyball	Ballistic bench throw (BBT) with 45% of bench press 1RM	Isometric bench press (IBP) (120° and 150° of elbow flexion)	Bilateral upper body	Ballistic bench press group (n=12): Pre: 0.65 ± 0.14, Post: 0.83 ± 0.20 Bench press group (n=12): Pre: 0.64 ± 0.15, Post: 0.73 ± 0.17
McMahon et al. (2017)	53M	Collegiate athletes (football and rugby union)	CMJ (self-selected depth, hands on hips, ‘as high and as fast as possible’)	IMTP (HA and KA: 140-150°)	Bilateral lower body	0.73 ± 0.19
Thomas et al. (2017a)	56M, 59F	Basketball, cricket, football, netball	CMJ (self-selected depth, hands on hips, ‘as high and as fast as possible’)	IMTP (KA: 130-150°, HA: 140-160°)	Bilateral lower body	M Basketball (n=17): 0.86 ± 0.13 M Cricket (n=23): 0.86 ± 0.21 M Football (n=16): 0.70 ± 0.16 F Netball (n=21): 0.89 ± 0.22 F Cricket (n=23): 0.91 ± 0.13 F Football (n=15): 0.80 ± 0.23

Reference	Population	Sport	Dynamic strength measure	Isometric strength measure	Type of DSI	DSI (Mean ± SD)
Comfort et al. (2018a)	14M, 10F	Rugby league, rowing, field hockey, and bicycle motocross	CMJ (self-selected depth, hands on hips, 'as high and as fast as possible')	IMTP (KA: 140.1± 3.6°, HA: 148.8± 4.1°)	Bilateral lower body	Pre-training: 0.71 ± 0.13 Post-training: 0.65 ± 0.11
Comfort et al. (2018b)	27M	Football and rugby league	SJ (self-selected depth, KA approximately 90°, hands on hips, 'aim to jump as high as possible'), CMJ (self-selected depth, hands on hips, 'aim to jump as high as possible')	IMTP (KA and HA: 140-150°)	Bilateral lower body	DSI-SJ Session 1: 0.76 ± 0.14 Session 2: 0.82 ± 0.18 DSI-CMJ Session 1: 0.86 ± 0.14 Session 2: 0.84 ± 0.15
Parsonage et al. (2018)	9M, 8F	Surfers	Dynamic push-up	Isometric push-up	Bilateral upper body	M (n=9): 0.79 ± 0.12 F (n=8): 0.84 ± 0.08
Suchomel et al. (2020)	88M, 67F	NCAA Division 1 baseball, soccer, tennis, track and field, basketball, volleyball, softball	CMJ (self-selected depth, polyvinyl chloride (PVC) pipe on shoulders, 'aim to jump as high as possible')	IMTP (KA: 125-135°, HA: 140-150°)	Bilateral lower body	M (n=88): 0.47 ± 0.08 F (n=67): 0.51 ± 0.08
Bishop et al. (2021a)	28M	Football and rugby	Unilateral CMJ (self-selected depth)	Unilateral ISQ (KA and HA: 140°)	Unilateral lower body	Left Session 1: 0.59 ± 0.26 Session 2: 0.55 ± 0.16 Right Session 1: 0.55 ± 0.17 Session 2: 0.52 ± 0.14
Haischer et al. (2021)	19F	Collegiate lacrosse	CMJ (self-selected depth, wooden dowel on shoulders, maximal effort)	IMTP (KA: 135°, HA: 145°)	Bilateral lower body	Force-based DSI: 0.75 ± 0.09 Impulse-based DSI: 0.77 ± 0.20

Reference	Population	Sport	Dynamic strength measure	Isometric strength measure	Type of DSI	DSI (Mean ± SD)
Ahn et al. (2022)	8F	NCAA lacrosse	CMJ (self-selected depth, hands on hips, 'as high and as fast as possible')	IMTP (KA: 145°, HA:135°)	Bilateral lower body	Not reported.
James & Comfort (2022)	23M	Resistance-trained participants	CMJ (self-selected depth, hands on hips, maximal effort)	ISQ (KA: 140°)	Bilateral lower body	DSI_{trad}: Trial 1: 0.59 ± 0.09, Trial 2: 0.59 ± 0.09 DSI_{prop}*: Trial 1: 0.78 ± 0.08, Trial 2: 0.79 ± 0.12 DSI_{peak}*: Trial 1: 0.60 ± 0.09, Trial 2: 0.60 ± 0.10 DSI_{100}*: Trial 1: 1.04 ± 0.11, Trial 2: 1.06 ± 0.14 DSI_{150}*: Trial 1: 0.94 ± 0.09, Trial 2: 0.95 ± 0.13
Pleša et al. (2023a)	19M, 9F	Recreationally active	CMJ (KA: approximately 90°, lightweight (<0.5kg) plastic bar on shoulders, 'jump as high as possible'), SJ (KA: 90°, same conditions as CMJ),	ISQ (KA: 30°,60° and 90°)	Bilateral lower body	CMJ DSI_{30}*: 0.64 ± 0.19 CMJ DSI_{60}*: 0.71 ± 0.14 CMJ DSI_{90}*: 1.11 ± 0.14 SJ DSI_{30}*: 0.56 ± 0.09 SJ DSI_{60}*: 0.62 ± 0.12 SJ DSI_{90}*: 0.99 ± 0.14
Pleša et al. (2023b)	32M	Basketball	Bilateral and unilateral CMJ (self-selected depth, hands on hips, 'jump as high as possible')	Bilateral and unilateral ISQ (KA: 90°)	Bilateral and unilateral lower body	Seniors (n=11) (Pre-season & in-season) DSI: 1.07 ± 0.12 & 1.00 ± 0.12 DSI-L: 1.21 ± 0.11 & 1.36 ± 0.32 DSI-R: 1.20 ± 0.15 & 1.33 ± 0.32 Juniors (n=21) (Pre-season & in-season) DSI: 1.14 ± 0.13 & 1.17 ± 0.15 DSI-L: 1.28 ± 0.15 & 1.31 ± 0.33 DSI-R: 1.22 ± 0.13 & 1.30 ± 0.32

Reference	Population	Sport	Dynamic strength measure	Isometric strength measure	Type of DSI	DSI (Mean ± SD)
Scheller et al. (2023)	28M, 58F	University athletes	CMJ (self-selected depth with KA: approximately 90°, (<0.5kg) wooden bar on shoulders, 'jump as high as possible without pausing')	IMTP (KA: 120-150°, HA:124-175°)	Bilateral lower body	Not reported.
Ong et al. (2024)	37 (gender not specified)	Floorball, cycling, taekwondo, basketball and badminton	CMJ (self-selected depth, hands on hips, 'jump as high and as fast as possible')	IMTP (KA:125-135°, HA: 140-150°)	Bilateral lower body	0.68 ± 0.10

Note. M= male, F= female, KA= knee angle, HA= hip angle. *indicates DSI calculated using an alternative method.

2.4.1 Strength measures used to calculate DSI

The majority of the studies (14/18) conducted on the DSI thus far have used it as a bilateral lower body assessment (Table 1). The bilateral lower body strength measures most commonly used are the CMJ and IMTP, with some studies utilizing the SJ and ISQ.

Within the studies that assessed reliability of measures, relative reliability was assessed using intraclass correlation coefficient (ICC) and absolute reliability using coefficient of variation (%CV) (Hopkins, 2009; Koo et al., 2016). ICC was classified as excellent (> 0.9), good (0.75-0.9), moderate (0.50– 0.75) and poor (< 0.5) (Koo et al., 2016). %CV was classified as acceptable if ≤ 10 (Cormack et al., 2008).

2.4.1.1 Bilateral lower body strength measures

All of the bilateral lower body DSI strength measures have been obtained via vertical ground reaction forces collected on force plates, due to the specified movements primarily occurring in the sagittal plane: the CMJ, SJ, IMTP and ISQ. Future research could potentially conceptualize lower body DSI strength measures in the frontal and transverse planes, where alternative technologies like strain gauges could prove to have utility due to their manoeuvrability.

The original dynamic strength measures used for the DSI as described by Young et al. (1995), involved a SJ or CMJ with a 9kg bar resting on the athletes' shoulders, performed at a 90° knee angle. The CMJ and SJ differ primarily in that the former involves initiating a countermovement before the jump, resulting in a higher PF_{dyn} and DSI value (Comfort et al., 2018b). Since then, DSI studies using the SJ have used a variety of knee angles during the set-up including 90° (Pleša et al., 2023a; Comfort et al. 2018b), 110° (Sheppard et al., 2011) and approximately 135° (Thomas et al., 2015b). These studies also differed in the way the SJ was executed, with Sheppard et al. (2011) and Pleša et al. (2023a) using a bar on the shoulders while Thomas et al. (2015b) and Comfort et al. (2018b) enforced hands on hips during the jump. Sheppard et al. (2011) and Thomas et al. (2015b) both found that the DSI obtained from the SJ and IMTP showed good between-session reliability, for sessions spaced 48 h apart. Intraclass correlation coefficients (ICC) were 0.95 and 0.97, while coefficients of variation (%CV) were 2.94 and 4.6, for the Sheppard et al. (2011) and Thomas et al. (2015) studies, respectively. Comfort et al. (2018b) compared the reliability of the DSI calculated using the CMJ (DSI-CMJ) with the DSI calculated using the SJ (DSI-SJ) over two sessions, using the IMTP as the isometric strength measure (for both conditions). The results of Comfort et al. (2018b) found that DSI-CMJ had better between-session reliability (ICC = 0.92) compared to the DSI-SJ (ICC = 0.74). In addition, the within-session reliability was high in both sessions for DSI-CMJ with low variability (ICC = 0.92 and 0.95, %CV = 4.57 and 3.80) while DSI-SJ showed moderate within session reliability and high variability (ICC = 0.42, %CV = 15.91) for the first session, that improved in the second session (ICC = 0.95, %CV = 4.03). Since these findings, the majority of studies (11/14) investigating bilateral lower body DSI have preferentially used CMJ as opposed to the SJ as the dynamic strength measure for the DSI (Table 1). Due to the more dynamic nature of the CMJ, there was an absence of knee angle standardisation, with athletes self-selecting the depth that would produce the best performance. However, both Pleša et al. (2023b) and Scheller et al. (2023) instructed participants to dip to a knee angle of approximately 90°. Similar to the SJ, the CMJ was performed with either a bar or implement on the shoulders (Sheppard et al., 2011; Suchomel et al., 2020; Haischer et al., 2021; Pleša et al., 2023a; Scheller et al., 2023) or hands on the hips (Thomas et al., 2015b; McMahon et al., 2017; Thomas et al., 2017a; Comfort et al., 2018a; Comfort et al., 2018b; Ahn et al., 2022: James & Comfort, 2022; Pleša et al., 2023b; Ong et al., 2024), to eliminate any arm-swing during the jump. For both SJ and CMJ, common instructions given to the athletes were 'jump as high as possible' and 'jump as fast and as high as possible' (Table 1).

The original isometric strength measure used for the DSI as described by Young et al. (1995), involved an ISQ performed at a 120° knee angle. Sheppard et al (2011) introduced the usage of the IMTP instead of the ISQ, with the reasoning that it provides a safer position to exert maximal force isometrically. Conversely, greater PF_{iso} can be produced in the ISQ compared to the IMTP (Sheppard et al. 2011; Pleša et al., 2023a). The majority of the studies (11/14) investigating bilateral lower body DSI have used the IMTP as the isometric strength measure (Table 1), with the ISQ being utilised by James & Comfort (2022), Pleša et al. (2023a) and Pleša et al. (2023b). These studies have investigated the ISQ at knee angles of 30° (Pleša et al., 2023a), 60° (Pleša et al., 2023a), 90° (Pleša et al., 2023a; Pleša et al., 2023b) and 140° (James & Comfort, 2022). With regards to within-session reliability, Pleša et al. (2023b) and James & Comfort found good relative reliability (ICC = 0.85 to 0.87) and acceptable absolute reliability (%CV = 5.72 to 6.33) for the DSI calculated using the ISQ. No study thus far has assessed between-session reliability of the DSI derived from the ISQ. Between-session and within session reliability of the DSI derived from the IMTP has been addressed earlier in the studies by Sheppard et al. (2011) and Thomas et al. (2015b). In the set-up for the IMTP, a range of knee and hip angles have been used over various studies, ranging between 120-150° for the former and 124-175° for the latter (Table 1). While not part of the reviewed studies, Comfort et al. (2019) gave general recommendations of setting up the IMTP: to first allow the athlete to self-organise in a position that would replicate the second pull start position in the clean, before adjusting for optimal knee angle (125-145°) and hip angle (140-150°) positions. One important thing to note is that the different hip and knee angles used in the IMTP set-up would affect the overall force production and potentially DSI values as a second-order calculation (Beckham et al., 2018). Pleša et al., 2023a also found that increasing ISQ knee angles from 30° to 90° led to higher PF_{iso} and lower DSI values as a result. As such, the differences in joint angles during the isometric measure set-up should be taken into account when comparing DSI values across studies.

With regards to the bilateral lower body DSI, majority of the studies (7/12) that reported the mean DSI values appear to fall within the moderate range of 0.60-0.80 as initially recommended by Sheppard et al. (2011) (Table 1). The moderate range trend was unsurprising, given that most of these studies were done on competitive athletes from a variety of sports requiring some form of explosive movement such as basketball and cricket. For instance, Thomas et al. (2017a) compared male basketball, cricket and football players as well as female football, cricket and netball players, and found that mean DSI values were in the high DSI range (>0.80) for all the different sport and gender categories other than male football players (0.70). On the other hand, James & Comfort (2022) investigated resistance trained participants and found a mean DSI value of 0.59, slightly crossing into the low DSI threshold of <0.6, which could be possibly attributed to these individuals typically partaking in more maximal strength training as compared to ballistic training. Conversely, Suchomel et al. (2020) assessed Division I National Collegiate Athletic Association (NCAA) athletes from a variety of sports: baseball, football, tennis, track and field, basketball, volleyball, softball, and found mean DSI values for male (0.47) and female (0.51) athletes, that would fall within the low DSI (<0.60) range. Pleša et al. (2023b) also found unusually high mean DSI values of >1 for basketball players during pre-season and in-season. Theoretically, this should not be feasible as forces exerted isometrically would be greater than that exerted dynamically (Sheppard et al., 2011). In addition, PF_{iso} in ISQ is typically higher than that of the IMTP, meaning that the high DSI values in this study would potentially be even larger if the usual isometric measure of the IMTP was used like most of the other reviewed studies (Sheppard et al., 2011).

It is currently unclear why the athletes in Suchomel et al. (2020) and Pleša et al. (2023b) appear to exhibit outlier DSI values when compared to the other reviewed studies given the relatively similar demographics, especially in the case of the latter study. However, these findings exemplify the need to obtain baseline DSI values for specific populations being tested as opposed to broad comparisons to general DSI values available in the literature.

2.4.1.2 Unilateral lower body strength measures

Despite most of the DSI lower body studies having been done bilaterally, Bishop et al. (2021) highlighted that movement demands in sport such as sprinting, jumping and change of direction are usually performed unilaterally. As such, this study conceptualised a novel unilateral lower body DSI protocol: using the unilateral CMJ as the dynamic strength measure and the unilateral isometric squat with 140° knee and hip angle as the isometric strength measure. Similarly, these strength measures were collected using vertical ground reaction forces on force plates. For between-session reliability of DSI, the study found moderate-to-good relative reliability (ICC = 0.71 to 0.79), unacceptable absolute reliability (%CV = 10.45 to 11.90%) when defining limbs as left and right, and acceptable absolute reliability (%CV = 7.54 to 8.42), when defining limbs via limb dominance. Pleša et al. (2023b) also assessed unilateral lower body DSI using the unilateral CMJ and unilateral ISQ, with the main difference from Bishop et al., (2021) being the knee angle used; 90° instead of 140°. Pleša et al. (2023b) found good relative reliability (ICC = 0.76 to 0.84) and acceptable absolute reliability (%CV = 4.37 to 6.13) when assessing within-session reliability of the DSI of the left and right limbs, during pre-season and in-season testing of basketball players. Mean DSI values range from 0.52 to 0.59 in Bishop et al. (2021) and 1.17 to 1.41 in Pleša et al. (2023b). Given that these are the only two known studies to the authors investigating unilateral lower body DSI at the point of writing, further research would have to be done to contextualize these values.

2.4.1.3 Upper body strength measures

Compared to studies investigating lower body DSI, there is a paucity in research investigating DSI in the upper body. Young et al. (2014) and Young et al. (2015) investigated the usage of the ballistic bench throw (BBT) as the dynamic strength measures and isometric bench press (IBP) as the isometric strength measure. BBT was conducted with 45% of the bench press one-repetition maximum (1RM). In these studies, vertical ground reaction forces were collected via force plates placed under the bench during the execution of the BBT and IBP, with the exercises conducted on a Smith machine. Elbow angles tested in the IBP for Young et al. (2014) were 60°, 90°, 120° and 150°, with the latter two angles used in Young et al. (2015) due to exhibiting the highest PF_{iso} values. Between-session reliability of the upper body DSI calculated from the BBT and IBP showed excellent relative reliability (ICC = 0.93) and acceptable absolute reliability (%CV = 3.5) (Young et al., 2014). Mean DSI values ranged from 0.64 to 0.83 in the different groups and conditions reported in Young et al. (2015). Young et al. (2015) also suggested for ⩾ 0.75 to be the DSI threshold beyond which increasing maximal strength is recommended. Parsonage et al. (2018) and Parsonage et al. (2020) devised an alternative form of assessing upper body DSI specific to the sport of surfing, with the isometric push-up (IPU) and dynamic push-up (DPU) serving as the isometric and dynamic strength measures respectively. Similarly, these movements were executed on a force plate with the vertical ground reaction forces acting on the upper body collected. Standardisation of arm position was done via alignment of thumbs with the armpit at approximately 100% of biacromial width in the prone position. While the reliability of the DSI metric itself was not reported, between-session reliability of the IPU and DPU showed excellent relative reliability (ICC = 0.90 to 0.96) and acceptable absolute reliability (%CV = 4.7 to 5.0) (Parsonage et al., 2020). Average DSI values from this surfing-specific upper body DSI were 0.79 in males and 0.84 in females (Parsonage et al., 2018). At the point of writing, these are the only two known validated forms of DSI for the upper body and they have both been conducted bilaterally, with no known unilateral upper body DSI assessment available.

2.4.2 Variants of DSI

One main criticism of the conventional DSI metric is that PF_{dyn} by itself does not include a temporal element; which may be a disadvantage as impulse actually predicts CMJ jump height better than PF_{dyn} during a CMJ (Haischer et al., 2021; James & Comfort, 2022). As such, Haischer et al. (2021) devised an impulse-based DSI (iDSI) to compare with the traditional force-based DSI (fDSI) for bilateral lower body strength assessment, using the ratio of the concentric impulse in the CMJ as the dynamic strength measure to the impulse in the IMTP as the isometric strength measure. Impulse during the concentric phase of the CMJ was calculated as follows in (2); where t_i and t_{to} represents concentric phase onset and takeoff, F_{GRF} represents total ground reaction forces and F_{BW} represents the subject's bodyweight:

$$\int_{t_i}^{t_{to}} F_{GRF}dt - \int_{t_i}^{t_{to}} F_{BW}dt \quad (2)$$

Impulse during the IMTP was calculated as follows in (3), where t_i represents time of IMTP initiation and t_{CMJ} represents the CMJ impulse time in (2), F_{onset} represents forces at IMTP onset:

$$\int_{t_i}^{t_{CMJ}} F_{GRF}dt - \int_{t_i}^{t_{CMJ}} F_{onset}dt \quad (3)$$

While the reliability of the iDSI metric itself was not assessed, its constituent components: CMJ concentric impulse and IMTP impulse showed excellent within-session reliability (ICC = 0.97 for both) (Haischer et al., 2021). Spearman's rho correlation found moderate positive correlations between fDSI and iDSI (r_s = 0.64, p= .003), with the strength of correlation suggesting that iDSI is a separate metric from fDSI. Among the subjects tested, 37% also faced conflicting training recommendations when comparing their iDSI and fDSI, using the 0.60 and 0.80 thresholds recommended by Sheppard et al. (2011). Further investigations into including a temporal element to the DSI include James & Comfort (2022) which compared four different DSI variants to the traditional DSI (DSI_{trad}), using the CMJ and ISQ as the dynamic and isometric strength measures. The four variants consist of; DSI_{prop}: ratio of the mean force over the CMJ propulsive phase to the mean force in the ISQ calculated across the propulsive phase duration of the CMJ; DSI_{peak}: ratio of the mean force over the CMJ propulsive phase to the mean force in the ISQ from initiation to peak force; DSI_{100}: ratio of the mean force over the first 100 ms of the CMJ propulsive phase to the mean force over the first 100 ms of the ISQ, as well as DSI_{150}: ratio of the mean force over the first 150 ms of the CMJ propulsive phase to the mean force over the first 150 ms of the ISQ. When assessing within-session reliability, these DSI variants showed moderate relative reliability (ICC = 0.63 to 0.74) and acceptable absolute reliability (%CV = 6.87 to 8.63), though they were less reliable than the DSI_{trad} (ICC = 0.85, %CV = 6.33). However, James & Comfort (2022) determined that relative reliability was not acceptable when looking at the 95% confidence interval of the ICC (0.31 to 0.48). Correlations with DSI_{trad} was near perfect for DSI_{peak} ($r = 0.94$, $p < 0.01$), large with DSI_{prop} ($r = 0.64$, $p < 0.01$), moderate with DSI_{150} ($r = 0.37$, $p = 0.08$) and small but insignificant with DSI_{100} ($r = 0.17$, $p = 0.45$). The strength of these relationships with DSI_{trad} appear to weaken with shorter time window of interests, as the earlier phases of force production would have diminished relationships with peak forces. As such, these DSI variants appear to be useful alternative tools for within-individual strength monitoring and not so much in comparison to a group, due to acceptable absolute reliability and limited relative reliability.

To date, DSI calculations have primarily been facilitated by ground reaction forces (GRF) collected using force plates. Ahn et al. (2022) highlighted that while GRF magnitude gives a good overall view of an athlete's physical capabilities, it is not always associated with net joint moments (NJM), which may provide greater utility and resolution of data as most sports involve multi-joint movements. As such, this study sought to compare the conventional DSI calculated via GRF (DSI_{GRF}) with DSI calculated using the peak /NJM at the hip, knee and ankle (DSI_{NJM}) via equation (4) shown below, with the kinetic and kinematic variables of the CMJ and IMTP captured using a 3D motion capture system:

$$DSI_{NJM} = \text{CMJ Peak } NJM_{Hip,Knee,Ankle} / \text{ IMTP Peak } NJM_{Hip,Knee,Ankle} \quad (4)$$

When assessing within-session reliability of DSI_{NJM}, this study found excellent relative reliability (ICC = 0.97 to 0.99) and acceptable absolute reliability (%CV = 3.5 to 6.8). Only DSI_{NJM} at the hip joint was found to be positively correlated to DSI_{GRF} ($r = .74$, $p < .05$), suggesting the DSI_{GRF} has limited utility for assessing joint-specific strength, with future research needed to assess the potential of DSI_{GRF} as an assessment of hip extensor strength. DSI_{NJM} at the hip, knee and ankle were 111%, 62% and 34% greater than DSI_{GRF} respectively, indicative of the proximal-to-distal force production sequencing of the lower body. In addition, DSI_{NJM} at all joints were all greater than 1.0, indicating that NJM of all joints during the CMJ was greater than NJM during the IMTP. These findings can be attributed to the fact that joint angles in the CMJ differ from that in the IMTP, which questions the suitability of using these two movements in the conventional DSI calculation.

With the limited literature in upper body DSI (as mentioned in 2.4.1.3), an alternative measure named the Dynamic Skill Deficit (DSD) has been proposed in assessing surfing-specific upper body dynamic strength in relation to isometric strength by Parsonage et al. (2018) and Parsonage et al. (2020). In addition to the IBP and DPU, a surfing-specific movement called the Force Plate Pop-up (FP POP), was also conducted, where subjects would pop-up from a prone position to their surfing stance on the same force plates. DSD was calculated as shown in (5):

$$DSD = PF_{dyn} \text{ in FP POP/ } PF_{iso} \text{ in IBP} \quad (5)$$

While the reliability of the DSD metric itself was not reported, between-session reliability of the IBP and FP PO showed excellent relative reliability (ICC = 0.90 to 0.96) and acceptable absolute reliability (%CV = 4.4 to 4.7) (Parsonage et al., 2020). Average DSD values from this surfing-specific upper body DSI variant were 0.72 in males and 0.79 in females (Parsonage et al., 2018). The work of Parsonage et al., 2020 showcased the possibility of including a more sport-specific dynamic strength assessment, which could be also explored in a variety of other sports.

2.5 Relationships between DSI and performance

The following section will address the associations between DSI and different performance measures found in the literature, the effect of training on DSI and the potential link between DSI with change of direction (COD) performance.

Correlation values were interpreted as trivial (< 0.10), small (0.10 to 0.29), moderate (0.30 to 0.49), large (0.50 to 0.69), very large (0.70 to 0.89) and nearly perfect (⩾ 0.90) (Hopkins et al., 2009).

2.5.1 Associations between DSI and various performance measures

Firstly, the relationships between DSI and its constituent components: PF_{dyn} and PF_{iso} were examined. The two studies examining this relationship in bilateral lower body DSI utilised the Spearman's rank order correlations due to some of the variables violating normality assumptions in the Shapiro-Wilk test (Suchomel et al., 2020; Scheller et al., 2023). Suchomel et al. (2020) found very large relationships between DSI with relative IMTP PF_{iso} (r_s = -0.85, p < .001 in males; r_s = -0.75, p < .001 in females) and moderate relationships between DSI with relative CMJ PF_{dyn} (r_s = 0.30, p = .005 in males; r_s = 0.31, p = .01 in females). Scheller et al. (2023) found large relationships between DSI with absolute IMTP PF_{iso} (r_s = -0.51, p ≤ .05) and relative IMTP PF_{iso} (r_s = -0.63, p ≤ .05), small relationships with relative CMJ PF_{iso} (r_s = 0.22, p ≤ .05) and insignificant relationships with absolute CMJ PF_{iso} (r_s = 0.11, p > .05). An overall trend could be observed in which the variance in bilateral lower body DSI could be better explained by PF_{iso} as opposed to PF_{dyn}, with the strength of these relationships being stronger when using relative instead of absolute PF_{iso} and PF_{dyn} values. Meanwhile, Parsonage et al. (2018) found that relationships between the IBP PF_{iso} and bilateral upper body DSI were insignificant (p > .05). In addition, no significant relationships were found between DSI and two performance measures commonly used to assess athletes: CMJ height and 10 m linear sprint time (p > .05). (Suchomel at al., 2020; Pleša et al., 2023b).

Next, three studies have also investigated the relationships between DSI and other measures typically used to assess the ballistic ability of athletes; such as the force-velocity profile, rate of force development (RFD), peak power (PP), modified reactive strength index (RSI_{mod}) and force production in the early epochs (Suchomel et al., 2020; Pleša et al., 2023a; Ong et al., 2024). Pleša et al. (2023a) investigated the relationships between DSI-CMJ and DSI-SJ at 3 different ISQ knee angles (30°, 60° and 90°) with the force-velocity profile in the CMJ and SJ. Pleša et al. (2023a) found moderate-to-large associations between maximal theoretical power (P_{max}) with all DSI values (r = 0.42 to 0.69; p < .05); maximal theoretical velocity (V_0) with all DSI-CMJ values and DSI-SJ at 30° knee angle (r = 0.43 to 0.56; p < .05) and the slope of the force-velocity relationship (S_{fv}) with DSI-CMJ at 30° and 90° knee angles (r = 0.40 to 0.43; p < .05). These findings suggest that DSI and force-velocity profiling are assessing similar physical qualities, which can be taken into consideration when individualising athletes' training. Ong et al. (2024) investigated the relationships between DSI and force production in the early epochs (50, 100, 150, 200, 250ms), expressed as a percentage of IMTP net force (%PF) and found trivial to small correlations but these relationships were non-significant (p > .05), showing that DSI and %PF are not interchangeable metrics. Suchomel et al. (2020) found moderate negative relationships between DSI with IMTP rate of force development (RFD) (r_s = -0.34, p = .001 in males; r_s = -0.34, p = .005 in females). These results suggest that as DSI increased due to increase in ballistic force production, IMTP RFD may actually decrease, though this finding should be inferred with caution due to the low degree of variance (11.5%) that is explained by IMTP. Small positive relationships were found between DSI and RSI_{mod} (r_s = 0.17, p = .024 in males; r_s = 0.27, p = .025 in females); calculated as the ratio between CMJ height with time to take-off and is often classified as an explosive strength trait (Suchomel at al., 2020). Trivial and non-significant relationships were found between DSI and CMJ peak power (PP), which was an unsurprising finding as a specific power value could be obtained via different combinations of force and velocity (Suchomel et al., 2020). As a whole, it appears that force-velocity profiling is the ballistic strength measure that has the greatest alignment with DSI.

2.5.2 Effect of training on DSI

A few studies thus far have attempted to investigate the effects of training on DSI, to assess the validity of the typical recommendations of focusing on ballistic strength for lower DSI (<0.60) and maximal strength for higher DSI (>0.80). With regards to bilateral lower body DSI, two studies have investigated the effect of maximal strength training on DSI over a sustained training period (Sheppard et al., 2011; Comfort et al., 2018a). Sheppard et al. (2011) tracked the progress of five elite athletes as case studies and found meaningful increases in IMTP PF_{iso} and changes in DSI after an eight/ten-week training period involving maximal strength training. Changes to the SJ PF_{dyn} were lower than the typical error (TE). Changes in DSI were all greater than the TE (0.03 to 0.14), indicating the robustness of the DSI in tracking changes in athletes' strength qualities. Comfort et al. (2018a) found that four weeks of strength training led to no significant increases in CMJ PF_{dyn}, small but significant increase in IMTP PF_{iso} ($p < 0.001$, $d = 0.38$), as well as a small but significant decrease in DSI from 0.71 to 0.65 ($p = .009$, $d = 0.50$). Comfort et al. (2018a) also divided the subjects into a low and high DSI group from their pre-test results and found that the low DSI group experienced no change in DSI while the high DSI group experienced a ~13% decrease in DSI. One possible explanation given was that the high DSI group had lower strength levels, indicated by their pre-test IMTP PF_{iso} and thus benefited more from the strength training with greater increases in IMTP PF_{iso} (Comfort et al., 2018a). As such, both these studies appear to support the idea of maximal strength training mainly having an effect on PF_{iso}, with not much effect on PF_{dyn}. The findings from Comfort et al. (2018a) also falls in line with the general DSI training recommendations of focusing on maximal strength training with a relatively higher DSI.

Meanwhile, no study to date has directly investigated the effect of ballistic training on bilateral lower body DSI. As such, two related studies were used to investigate this theory (Cormie et al., 2010: McMahon et al., 2017). While not a training study by itself, McMahon et al. (2017) lends support to the idea of focusing on ballistic strength for low DSI athletes and maximal strength for high DSI athletes. For the investigation, the force-time, power-time, velocity-time and displacement-time curves between a low mean DSI (0.55) and high mean DSI (0.92) group of athletes were compared. The low DSI group had a higher IMTP PF_{iso} compared to the high DSI group that was statistically significant. Both groups differed in their CMJ kinetics and kinematics; with the low DSI group exhibiting a larger braking net impulse, greater braking velocity and countermovement displacement in the CMJ. As such, the low DSI group should theoretically benefit from more ballistic training to assist in the braking-propulsion coupling phase kinetics. Cormie et al. (2010) investigated the effects of a 10-week ballistic training program on two groups split by their relative back squat 1RM. The study found that while both CMJ PF_{dyn} improved for both the stronger group (1RM of 1.97x bodyweight) and the weaker group (1RM of 1.32x bodyweight), the stronger group had greater improvements. In addition, there was a reduction in back squat 1RM for the stronger group and slight increase for the weaker group. Though DSI and IMTP PF_{iso} were not assessed in the study, the stronger group would likely have a lower DSI pre-test and thus benefitted more from the ballistic training. While these studies (Cormie et al., 2010; Mcmahon et al., 2017) provide solid theoretical backing to support the training recommendations, direct evidence with regards to ballistic training benefitting athletes with lower DSI is still lacking and future research would be required to ascertain this claim.

For upper body DSI, Young et al. (2015) is the only known study to investigate the direct effects of training on DSI. As mentioned earlier in 2.4.1.3, the IBP was used to assess PF_{iso} and the BBT was used to assess PF_{dyn}. For this investigation, the effect of two different training interventions over 5 weeks were examined: ballistic strength training group using the BBT and maximal strength training group using the bench press (BP). Participants were further split into 4 groups based on their DSI and intervention: high DSI BBT, low DSI BBT, high DSI BP and low DSI BP. Both BBT and BP training groups saw significant increases in DSI, BBT PF_{dyn} and IBP PF_{iso} after 5 weeks of training. Larger relationships were found between starting DSI and the % change in performance for the low DSI BBT group (r = 0.59), compared with the low DSI BP group (r = 0.29). These findings suggest that ballistic strength training had a greater impact than maximal strength training for the low DSI athletes. Furthermore, larger associations were found between starting DSI and the % change in performance for the high DSI BP group (r = 0.80), compared to the high DSI BBT group (r = 0.57), indicating that maximal strength training had a larger effect than ballistic strength training for the high DSI athletes. Therefore, this study supports the general DSI training guidelines of prescribing ballistic training to athletes with lower DSI and maximal strength training to athletes with higher DSI.

2.5.3 Possible relationships between lower body DSI and COD performance

Change of direction (COD) is an essential ability in many court and team sports, involving a variety of neuromuscular capabilities: concentric, isometric, eccentric and reactive strength, with eccentric strength having the highest correlation with 180° COD performance (Ryan et al., 2022; Spiteri et al., 2014). While the relevant angles and speeds of COD vary depending on the sport, sharper COD angles of ⩾ 135° are more related to slow stretch-shortening cycle (SSC) actions due to their relatively longer ground contact times, which appear to be improved by ballistic exercises of > 0.25s that build slow reactive strength (Dos Santos et al., 2018). This increased ground contact time also allows more time for force expression, allowing greater contribution from maximal strength qualities (Ryan et al., 2021). Intuitively, this aligns well with the theoretical underpinnings of the DSI, with the CMJ being characterised as a slow SSC movement with eccentric elements involved in the countermovement phase (Van Hooren & Zolotarjova, 2017). Therefore, the following section will primarily focus on the possible relationships between lower body DSI with the two most common tests assessing the sharpest COD angle of 180°: the traditional 505 agility (tra505) and modified 505 agility tests (mod505) (Ryan et al., 2022).

To date, only one known study has directly investigated the relationship between lower body DSI and 180° COD performance. Pleša et al., 2023b investigated both bilateral and unilateral lower body DSI, with COD performance measured using the tra505 and change of direction deficit (CODD). DSI was measured using bilateral and unilateral CMJ along with the ISQ. The authors did not identify leg dominance for this study. No significant correlations were found between bilateral DSI with COD performance during the pre-season period and between unilateral DSI with COD performance at any time point. During the in-season, significant moderate correlations were found between bilateral DSI with tra505 on the left and right legs (*r* = 0.37 and 0.36) and CODD on the right leg (*r* = 0.39). Interestingly, the only relationships between CMJ PF_{dyn} with COD performance at any time-point was with tra505 on the left leg (*r* = -0.42 in pre-season and -0.34 in the in-season). Lower values of DSI appeared to correspond with better COD performance during the in-season, with greater relationships between COD performance with relative ISQ PF_{iso} (*r* = -0.43 to -0.54) than with relative CMJ PF_{dyn}. These findings seem to suggest that the PF_{iso} was more related to COD performance than PF_{dyn}. Interestingly, no significant correlations were found between relative ISQ PF_{iso} and the COD variables during the pre-season.

Due to the abovementioned lack of direct investigation into the DSI's relationship with 180° COD performance, this section will address the associations between 180° COD and one of its constituent elements, IMTP PF_{iso}. Firstly, Thomas et al. (2015a) found a large correlation (*r* = -0.57) between absolute bilateral IMTP PF_{iso} with the mod505 in male collegiate football and rugby league players. Next, Thomas et al. (2016) investigating male cricket players found no significant relationships between relative unilateral and bilateral IMTP PF_{iso} with the mod505; with moderate-to-large correlations between relative unilateral IMTP PF_{iso} with tra505 on both legs (*r* = -0.47 to -0.65) and moderate correlations between relative bilateral IMTP PF_{iso} with tra505 on the left leg (*r* = -0.49). One possibility for this finding was the higher approach velocity in the tra505 compared to the mod505, that may require greater maximal isometric strength for efficient deceleration. In contrast, Thomas et al. (2018) reported moderate-to-large relationships between relative bilateral IMTP PF_{iso} with COD performance in both tra505 and mod505 for male team sport athletes (*r* = -0.36 to -0.57) and no significant relationships between relative IMTP PF_{iso} for the female team sport athletes. A possible rationale for these findings were the varied demographics of the participants and that only the COD performance of the dominant limb was tested. To summarize, there appears to be a general negative relationship between IMTP PF_{iso} and COD performance in the mod505 and tra505, with the strength and significance of the relationship varying between demographics.

Unlike the IMTP PF_{iso}, there is a dearth in the literature regarding the link between 180° COD and CMJ PF_{dyn}, with the only known relationship being addressed by Pleša et al. (2023b) above.

Interestingly, the strength of relationship between CMJ PF_{dyn} and tra505 actually decreased during from the pre-season to the in-season in this study. Despite this, there have been several studies investigating the relationships between different CMJ variables with COD and deceleration. Harper et al. (2020) investigated if CMJ neuromuscular properties could differentiate maximal horizonal deceleration ability among team sport athletes. The results of Harper et al. (2020) showed that CMJ PF_{dyn} was the variable showing the largest difference between the high and low horizontal deceleration ability groups (effect size (ES) = 0.95, p = .02), with horizontal deceleration ability measured by average deceleration. In addition, CMJ height has been found to have a relationship with 180° COD ability; Castillo-Rodríguez et al. (2012) found large correlations (r = -0.60, p = .01) between CMJ height and mod505 on the dominant side of football players and Thomas et al. (2017b) found large-to-very large significant correlations (r = -0.60 and -0.71) between CMJ height and tra505 on the right and left leg respectively for female netball players. When assessing female football players, Lockie et al. (2018) also found large correlations (r = -0.66, p < .01) between tra505 with CMJ height and CMJ peak power (r = -0.64, p < .01). One pertinent point to note is that CMJ height is largely determined by impulse and has been found to be not significantly correlated to CMJ PF_{dyn} by Barker et al. (2018).

Evidently, the CMJ movement appears to have some relationship with 180° COD ability, both from a theoretical neuromuscular basis as well as having literature demonstrating several of these relationships; with scope for further research to see if this link extends to the CMJ PF_{dyn} and the DSI.

2.6 Conclusion

To conclude, this literature review explored the different forms, methodology and variants of the DSI. Majority of the DSI studies were conducted on lower body DSI, which was most commonly measured using the IMTP and CMJ. Links were found between DSI and other ballistic strength measures like the CMJ force-velocity profile and rate of force development. Additionally, several training studies demonstrated alignment with the DSI guidelines of low DSI (<0.60) individuals requiring more ballistic strength training and high DSI (>0.80) individuals requiring more maximal strength training. In contrast, limited research has investigated the relationships between DSI and COD. Given the relationships between several variables of the CMJ and COD performance, as well as the theoretical prominence of the slow SSC in both these movements, there is potential for further research in this area.

Chapter 3: Pre-season testing of professional male football players

3.1 Preface

As addressed in Chapter 2, the Dynamic Strength Index (DSI) has been shown to be a reliable metric that has been linked to different sport performance measures, with theoretical underpinnings that may possibly link it to change of direction (COD) ability. This chapter aims to investigate this relationship through a series of pre-season physical assessments involving professional male football players.

3.2 Introduction

Football is an intermittent sport primarily consisting of lower intensity, aerobically-demanding movements that is interspersed with 1000-1400 higher intensity, anaerobically-taxing activities that occurs every 4 to 6 seconds within a game (Stølen et al., 2005). Sprinting in football takes place roughly every 90 seconds and lasts between 2 to 4 seconds per sprint; 96% of sprint bouts occur below 30 m and 49% occur below 10 m, indicating that these two sprint distances (10 m and 30 m) are useful metrics in assessing football-specific sprint performance (Stølen et al., 2005).

Change of direction (COD) is another important aspect of football, where 12-16% of total player load consists of acceleration and deceleration movements (Dalen et al., 2016). Rapid horizontal deceleration is a key component of COD and constitutes different kinematic and kinetic demands from that of linear acceleration in sprinting, with peak levels of muscle activation exceeding that of maximal voluntary isometric contractions (Hewit et al., 2011; McBurnie et al., 2022). Despite their short durations, high intensity deceleration movements have been shown to exhibit the highest mechanical load per meter: 65% more than any other game play movements (Dalen et al., 2016). The Illinois Agility test (IAT) is a common test used to assess COD ability in football (Amiri-Khorasani, 2010). One criticism of this test is that the large number of CODs (11) and long duration (13-19s) makes it difficult to isolate COD ability of the athlete (Nimphius et al., 2018). Lower body biomechanical demands peak during a COD at the highest velocities and sharpest angles (Dos Santos et al., 2018). This makes the sharpest possible COD angle of 180°, a critical measure in monitoring performance and injury risk. To assess 180° COD ability, the modified 505 (mod505) test is a reliable and valid test involving a 5 m to-and-fro sprint separated by a 180° COD (Dos' Santos et al., 2020).

Similar to most conventional COD tests, one limitation of the mod505 is that the majority of the timing constitutes linear sprinting rather than actual COD (Nimphius et al., 2013; Clarke et al., 2022). As such, the COD Deficit (CODD) was created to better isolate COD ability: the difference between mod505 time and a maximal 10 m linear sprint of equivalent distance (Nimphius et al., 2013; Nimphius et al., 2016). Subsequently, Ryan et al. (2021) introduced the sub-phase analysis of the mod505 test as an alternative way to isolate the different phases within the mod505 using additional timing splits. To date, there are no known studies comparing these two supplementary COD metrics in the mod505 test: CODD and the sub-phase analysis. In addition, one unique element of football is that most players would tend to have a dominant leg primarily used for kicking and performing other actions (Rouissi et al., 2016; Clemente et al., 2022). Clemente et al. (2022) found that young, highly-trained male football players performed better using their dominant (D) leg compared to the non-dominant (ND) leg in the traditional 505 agility test (tra505). As such, differentiation between performances of the two legs would be useful when assessing COD in football.

Gym-based assessments are common proxy measures for direct field-based assessments mentioned above, used to safely and conveniently assess athletes' physical abilities. Two gym-based assessments in particular: isometric mid-thigh pull (IMTP) and countermovement jump (CMJ), have been shown to have relationships with sprinting and COD performance in football, with the most commonly tracked CMJ measure being CMJ height (Haugen et al., 2012; Comfort et al., 2014; Köklü et al., 2015; Mason et al., 2021). In addition, the ratio of the peak force in the CMJ to the peak force in the IMTP has been shown to be a reliable method of calculating the Dynamic Strength Index (DSI): an assessment of an athlete's ability to produce force dynamically in comparison to their total maximal strength capability (Sheppard et al., 2011; Comfort et al., 2018; Suchomel et al., 2020). A low DSI ratio (⩽0.60) indicates that the athlete will require more ballistic strength training and a high DSI ratio (⩾0.80) would indicate the need for more maximal strength training (Sheppard et al., 2011; McMahon et al., 2017). To date, only one known study has directly investigated the relationship between lower body DSI and 180° COD performance (Pleša et al., 2023b), where significant moderate relationships were found between bilateral lower body DSI and tra505 performances during the in-season but not the pre-season. No known studies have investigated the relationship between DSI and the mod505. In addition, Pleša et al., 2023b used the isometric squat (ISQ) to determine the DSI, with no known studies investigating this relationship using the IMTP.

Thus, the primary research aim of this study was to: 1) investigate the relationships between DSI and its components with CMJ height, sprinting, COD and deceleration ability in professional male football players. The secondary research aims were to investigate: 2) possible differences between the D and ND legs during the mod505 test and 3) the possible relationships between the different supplementary COD measures in the mod505; the CODD and sub-phase analysis using additional timing splits. Taking into consideration the findings of Pleša et al. (2023b), we hypothesized that for

1), there will be either no significant relationship or a positive moderate relationship between DSI and COD measures. We hypothesized that for 2), COD performance will be better on the dominant leg and for 3), there will be significant relationships between CODD and some of the sub-phases of the mod505.

The results of this investigation will assess the effectiveness of using the DSI as a diagnostic tool for sprinting, COD and deceleration ability in football. In addition, the relationships between the different gym-based and field-based assessments will provide greater clarity regarding the diagnostic value of each test.

3.3 Methods

3.3.1 Experimental approach to the problem

This was a cross-sectional study that aimed to investigate the relationships between different physical measures via the use of correlations. The initial participant recruitment criteria was broad but eventually narrowed down to professional football players to allow comparison across a more homogenous demographic. The gym-based assessments involved in the study were the CMJ and IMTP and the field-based assessments involved in the study were the mod505, IAT and 30 m linear sprint.

3.3.2 Participants

Sample size was estimated via the G*Power (G*Power 3.1, University Kiel, Germany) statistical analysis program using the correlation: bivariate normal model. With reference to Thomas et al. (2015a), in order to detect a large effect size of $r = .57$ with inputs of Power (1-β-err prob) = 0.80 and α-error probability = 0.05, an estimated sample size of 17 participants was required. 19 male professional football players (age = 25.4 ± 4.1 years) playing in the same team of the Singapore Premier League were recruited during their pre-season training period of the 2024 season. The inclusion criteria were: 1) an active, well-trained male or female athlete in Singapore (aged 18-35 years), 2) have no history of lower body injury in the past 6 weeks, 3) are not a student of, or athlete directly working with any of the named researchers and 4) are in a land-based sport that has a change of direction element. Well-trained was defined as: currently engaging in structured sport training ≥ 2x a week and has competed in official competitions. The professional football team was identified as they fulfil the above conditions and would allow for even comparison across a similar demographic. The study was approved by the Auckland University of Technology Ethics Committee

(AUTEC); reference number 23/251. The purpose, risks and procedures were explained to the participants prior to written informed consent being obtained. Local ethics clearance was also obtained via the Singapore Sport Institute's Institutional Review Board before commencement of the study.

3.3.3 Testing protocol

Data collection was conducted over a single testing session, within the training facility of the professional football team. When the participants arrived, they underwent a standardised full body warm-up; specific test warmups were conducted before the individual gym-based and field-based assessments (refer to 3.3.3.1 and 3.3.3.2, respectively). Demographic information of the participants (age and preferred kicking leg) was collected before their height and weight were measured using a stadiometer and force plates (ForceDecks, VALD Performance, Queensland, Australia) respectively. Participants first completed the gym-based assessments in the gym of the training facility, before heading out to the synthetic soccer pitch for the field-based assessments. This same soccer pitch was used for the participants' training and official home league matches, enhancing ecological validity of the study. Participants were familiar with the gym-based and field-based assessments prior to data collection.

3.3.3.1 Gym-based assessments

There were two main components of the gym-based assessments: the CMJ and the IMTP. Both assessments were conducted on dual force platforms (ForceDecks, VALD Performance, Queensland, Australia) with a sampling rate of 1000 Hz. The IMTP was conducted with the participants strapped to a barbell using lifting straps and pulling the immoveable bar against the adjustable safety pins of a customised rack in the gym (Wang et al, 2016; Townsend et al., 2019). CMJ was assessed before IMTP, with 5 min of rest between the two tests.

For the CMJ trials, participants performed two warmup CMJ trials: one at self-ascertained 50% and one at 75% of maximal effort, separated by 1 min of rest; followed by two maximal-effort test trials separated by 2 min of rest; where participants kept their hands on the hips and dipped to a self-selected depth, before jumping as high as possible (Thomas et al., 2017a). CMJ absolute peak force (aPF) was taken as the maximum force value during the concentric phase of the CMJ and relative peak force (rPF) was calculated via dividing aPF by the participant's bodyweight. CMJ-H was calculated using the VALD software; from the velocity of the centre of mass at take-off using the impulse-momentum theorem.

For the IMTP trials, participants were instructed to self-organise in a position that would replicate the second pull start position in the clean, before adjusting the safety pins to ensure optimal knee angle (125-145°) and hip angle (140-150°) positions (Comfort et al., 2019). Participants performed two warmup IMTP trials: one at 50% and one at 75% of maximal effort, separated by one min of rest; followed by two maximal-effort IMTP test trials separated by 2 min of rest, where participants were instructed to pull against the bar while driving their feet into the force plate as hard as possible for 5s, with strong verbal encouragement during the trials (Halperin et al., 2016; Thomas et al., 2017a). IMTP absolute peak force (aPF) was taken as the maximum force value obtained during the force-time curve of the pull and relative peak force (rPF) was calculated via dividing aPF by the participant's bodyweight. A third trial was conducted if the difference in IMTP aPF between the two trials was >250N (Comfort et al., 2019).

The variables taken for analyses were: IMTP aPF, IMTP rPF, CMJ aPF, CMJ rPF and CMJ-H. DSI was calculated as: CMJ aPF/ IMTP aPF.

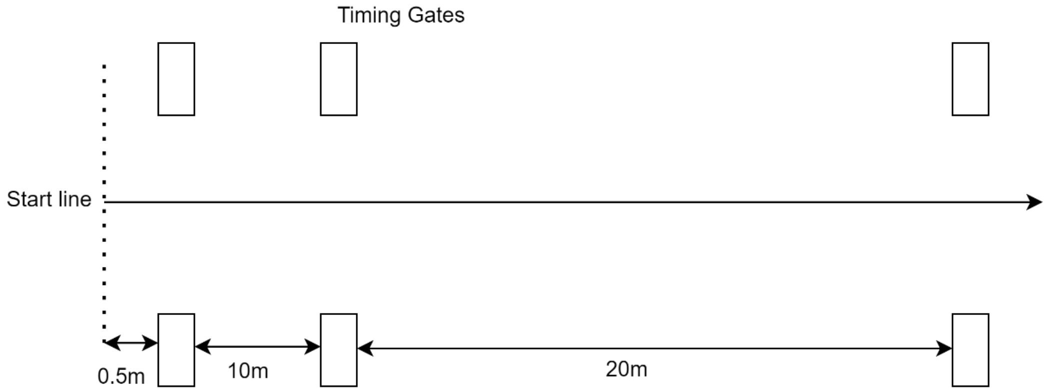
3.3.3.2 Field-based assessments

There were three main components of the field-based assessment: 30 m linear sprint, mod505 and IAT. Dual beam timing gates (Swift Performance Equipment, New South Wales, Australia) were used for all the field-based assessments. Timing gate height was set at 1m, roughly in line with participants' center of mass. Timing data was captured to the nearest 0.001s and presented as the nearest 0.01s for this paper. The participants completed the 30 m linear sprint and mod505 in a randomised order, before performing the IAT.

The timing gates setup of the 30 m linear sprint is shown below in Figure 1. Participants started with a two-point staggered stance with their front foot at the start line located 0.5 m behind the first timing gate and performed two trials of maximal effort sprints past the last timing gates, separated by 5 min of rest. one familiarisation trial was conducted before the two test trials. The total 30 m sprint time and timing split of the first 10 m (10 m sprint time) were taken for analyses.

Figure 1

30 m linear sprint setup



For the mod505 test, additional timing gates were set up as shown in Figure 2 to replicate the exact setup for sub-phase analysis from Ryan et al. (2021), where moderate-to-excellent inter-session relative reliability was reported for the subphases via intraclass correlation coefficients (ICC = 0.57 to 0.98). The different splits and sub-phases they represent are described in Table 2. Due to certain limitations of the set-up, the 180° COD and initial reacceleration splits were pooled together to form the sub-phase S3 for the current study. These limitations will be addressed in the discussion section.

Participants started with a two-point staggered stance with their front foot at the start line located 0.5 m behind the first timing gate and sprinted to the turning line, where they had to perform a 180° COD and sprint back past the first timing gate. one familiarisation trial turning on each leg was conducted before two test trials per leg, the order of which was randomised. 5 min of rest was given between test trials. Overall mod505 timing was labelled as COD and CODD was calculated via subtraction of the 10 m linear sprint timing. Suffixes of (-D) and (-ND) were used to label the dominant and non-dominant legs respectively. The COD and CODD, as well as sub-phase splits were taken for analyses.

Figure 2

Mod505 Test with adapted sub-phase analysis setup

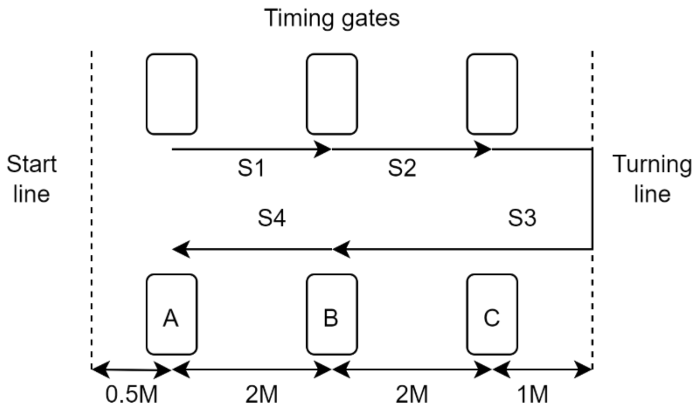


Table 2

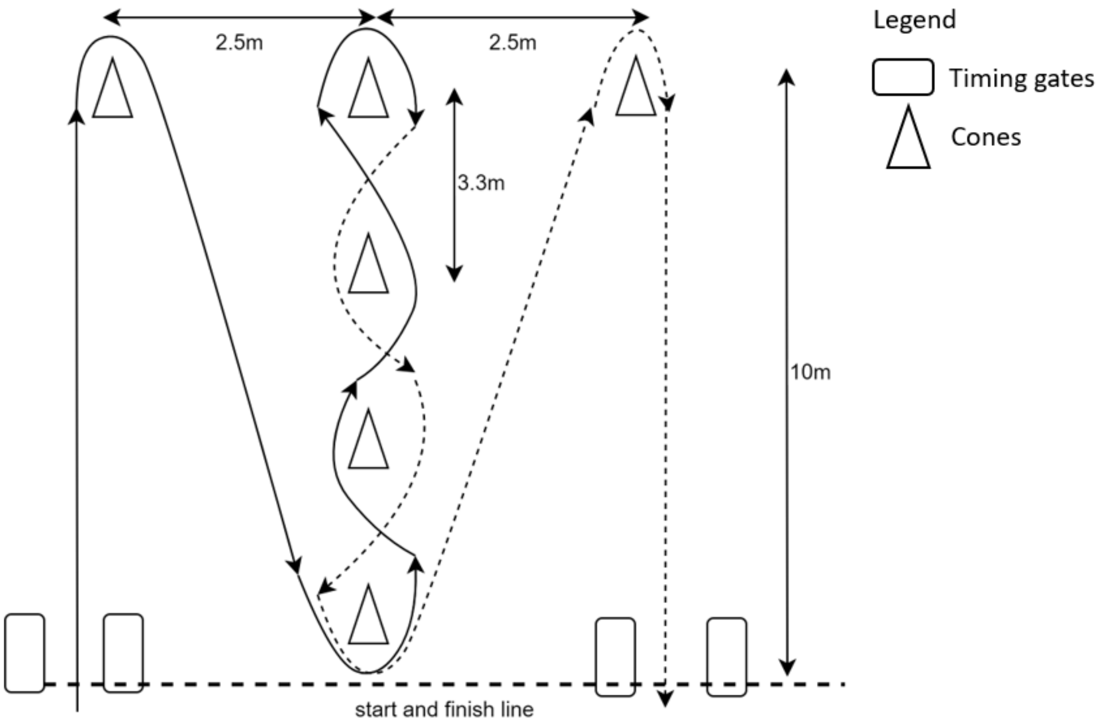
Description of splits and sub-phases in mod505

Split	Description	Sub-phase
S1	From start line to timing gate B	Initial acceleration
S2	From timing gate B to C	Deceleration
S3	From timing gate C to turning line, back to timing gate B	180° COD and initial reacceleration
S4	From timing gate B back to A	Second reacceleration

The IAT was set up as shown in Figure 3, where participants started with a two-point staggered stance with their front foot at the start line located 0.5 m behind the first set of timing gates, performed a series of sprints and CODs before sprinting past the second set of timing gates. Participants performed one familiarisation trial followed by two test trials and total IAT time was taken for analysis. 5 min of rest was given between test trials.

Figure 3

Illinois Agility Test setup



3.3.4 Statistical analysis

The trial with the best performance of each test was selected for further statistical analysis; highest aPF for CMJ and IMTP, as well as the fastest timing for the field-based assessments. Data was analysed using IBM SPSS Statistics (Version 26). All variables were assessed using the Shapiro-Wilk test, where all variables fulfilled the assumptions of normality ($p > .05$). The Pearson's correlation test was used to analyse the relationships between variables and a paired t-test was used to analyse differences between the timing splits of the D and ND legs. Correlation values were interpreted as trivial (< 0.10), small (0.10 to 0.29), moderate (0.30 to 0.49), large (0.50 to 0.69), very large (0.70 to 0.89) and nearly perfect (⩾ 0.90) (Hopkins et al., 2009). Due to the low sample size of the study (<20), effect sizes of the paired t-test were interpreted using Hedges' *g*, with the thresholds set at small (0.2), medium (0.5) and large (0.8) (Hedges and Olkin, 1985). Statistical significance was set at $p \leq .05$ for all analyses.

3.4 Results

The descriptive details of the participants are indicated in Table 3 and Table 4. Significant differences were found in the COD (0.05s), CODD (0.05s) and S3 phase (0.05s) between the D and ND legs, where the D leg was significantly faster (Table 4). Effect sizes of differences were small for all three measures.

There were no significant correlations between DSI and any of the sprint and COD measures (Table 5). CMJ-H had moderate-to-large significant negative correlations with multiple sprint and COD variables: 10 m sprint (r = -0.51), S2-D (r = -0.49), S4-D (r = -0.56), S4-ND (-0.46) and IAT (r = -0.62), as well as very large correlations with 30 m sprint (r = -0.80). There was a large significant negative correlation found between IMTP rPF and IAT (r = -0.54).

For the different COD measures (Table 6), there were very large significant positive correlations between the COD and CODD timings for both D (r = 0.80) and ND (r = 0.83) legs. The S3 splits for the respective legs had a nearly perfect significant positive correlation with COD-D (r = 0.90) and COD-ND (r = 0.93), as well as a very large significant positive correlation with CODD-D (r = 0.80) and CODD-ND (r = 0.81). In addition, S2-ND had large significant negative correlations with COD (r = -0.59) and CODD (r = -0.52). The IAT displayed a significant moderate correlation with COD-D (r = 0.46) and no significant correlations with COD-ND (Table 6).

Within the gym-based measures (Table 7), DSI had a very large significant negative correlation with IMTP rPF (r = -0.76) and a large significant correlation with IMTP aPF (r = -0.57), with no significant correlations with any of the CMJ variables. IMTP aPF had large significant positive correlations with IMTP rPF (r = 0.51) and CMJ aPF (r = 0.53). Interestingly, CMJ rPF had a moderate significant positive relationship with IMTP rPF (r = 0.48) and no significant relationship with CMJ aPF. There were no significant relationships between CMJ-H with any of the other gym-based measures.

Between the COD and sprint measures (Table 8), large significant correlations were found between the IAT with 10 m linear sprint (r = 0.53) and 30 m linear sprint (r = 0.67), whereas only moderate significant correlations were found between COD-ND with 10 m linear sprint (r = 0.48) and 30 m linear sprint (r = 0.46), with no significant correlations between COD-D and the sprints. No significant correlations were found between CODD on both legs with the sprints as well.

Table 3

Descriptive data of participant information and all the tests excluding the mod505

	Mean	SD
Body Mass (kg)	71.47	10.29
Height (m)	1.75	0.07
CMJ absolute PF (N)	1847.26	236.52
CMJ relative PF (N/kg)	26.01	2.60
IMTP absolute PF (N)	2626.26	385.18
IMTP relative PF (N/kg)	37.17	5.93
DSI	0.71	0.10
CMJ-H (cm)	38.85	5.16
10 m sprint (s)	1.72	0.08
30 m sprint (s)	3.77	0.16
IAT (s)	14.97	0.57

Table 4

Descriptive data and paired t-test differences between dominant (D) and non-dominant (ND) legs in the mod505

	Dominant leg (D)		Non-dominant leg (ND)						Effect size
Paired t-test	Mean	SD	Mean	SD	Mean difference	95% CI	t	p	Hedges' g
COD (s)	**2.36**	0.13	2.40	0.14	-0.05*	-0.09 to 0.00	-2.19	.03	0.34
CODD (s)	**0.64**	0.12	0.69	0.12	-0.05*	-0.09 to 0.00	-2.19	.03	0.38
S1 (s)	0.49	0.04	0.50	0.04	-0.01	-0.03 to 0.01	-0.95	.39	0.21
S2 (s)	0.49	0.03	0.48	0.04	0.01	0.00 to 0.03	1.54	.13	0.37
S3 (s)	**0.98**	0.13	1.03	0.17	-0.05*	-0.10 to -0.01	-2.33	.03	0.34
S4 (s)	0.40	0.03	0.40	0.03	0.00	-0.01 to 0.02	0.17	.89	0.03

Note. Statistical significance is indicated beside the mean difference value by * at $p \leq .05$ and **bold** indicates faster time.

Table 5

Pearson's correlations between gym-based and field-based assessments (sprint and COD)

	10 m sprint	30 m sprint	COD -D	CODD -D	S1 -D	S2 -D	S3 -D	S4 -D	COD -ND	CODD -ND	S1 -ND	S2 -ND	S3 -ND	S4 -ND	IAT
DSI	0.11	0.29	-0.06	-0.15	-0.17	0.26	-0.13	0.23	-0.05	-0.13	-0.11	-0.09	0.04	-0.14	0.37
CMJ rPF (N/kg)	-0.31	-0.06	-0.39	-0.23	-0.19	-0.01	-0.36	0.12	-0.15	0.03	0.35	0.11	-0.22	-0.06	-0.27
CMJ aPF (N)	0.27	0.29	-0.14	-0.33	-0.09	0.31	-0.23	0.27	0.02	-0.15	0.18	0.03	-0.01	-0.07	0.26
IMTP rPF (N/kg)	-0.30	-0.32	-0.20	-0.02	0.01	-0.20	-0.12	-0.16	-0.03	0.17	0.32	0.10	-0.14	0.10	-0.54 *
IMTP aPF (N)	0.16	-0.02	-0.08	-0.19	0.04	0.05	-0.09	0.00	0.06	-0.04	0.24	0.10	-0.04	0.05	-0.14
CMJ -H (m)	-0.51 *	-0.80 **	-0.31	-0.01	-0.06	-0.49 *	-0.03	-0.56 *	-0.16	0.15	-0.19	-0.14	0.02	-0.46 *	-0.62 **

Note. Statistical significance is indicated below the coefficient values by * at p ≤ .05 and ** at p ≤ .01.

Table 6

Pearson's correlations between different COD measures

	COD-D	CODD-D	S1-D	S2-D	S3-D	S4-D	IAT
COD-D (s)	-	0.80**	0.05	0.08	0.90**	0.21	0.46*
CODD-D (s)	-	-	-0.00	-0.02	0.80**	-0.04	0.15
	COD-ND	CODD-ND	S1-ND	S2-ND	S3-ND	S4-ND	IAT
COD-ND (s)	-	0.83**	0.23	-0.59**	0.93**	-0.06	0.35
CODD-ND (s)	-	-	0.10	-0.52*	0.81**	-0.17	0.05

Note. Statistical significance is indicated beside the coefficient values by * at p ≤ .05 and ** at p ≤ .01.

Table 7

Pearson's correlations between different gym-based measurements

	DSI	CMJ rPF	CMJ aPF	IMTP rPF	IMTP aPF	CMJ-H
DSI	-					
CMJ rPF (N/kg)	0.18	-				
CMJ aPF (N)	0.40	0.25	-			
IMTP rPF (N/kg)	-0.76**	0.48*	-0.22	-		
IMTP aPF (N)	-0.57*	0.06	0.53*	0.51*	-	
CMJ-H (m)	-0.38	0.06	-0.26	0.41	0.12	-

Note. Statistical significance is indicated beside the coefficient values by * at p ≤ .05 and ** at p ≤ .01.

Table 8

Pearson's correlations between sprint and COD measures

	COD-D	CODD-D	COD-ND	CODD-ND	IAT
10 m sprint (s)	0.45	-0.18	0.48*	-0.10	0.53*
30 m sprint (s)	0.40	-0.10	0.46*	0.00	0.67*

Note. Statistical significance is indicated beside the coefficient values by * at p ≤ .05 and ** at p ≤ .01.

3.5 Discussion

Sprinting, COD and deceleration abilities are vital physical aspects in football and are commonly assessed via field-based assessments like the mod505, IAT and 30 m linear sprint test. Besides field-based assessments, gym-based assessments such as the CMJ and IMTP are commonly used to assess football players' physical capabilities, using metrics like peak force, DSI and CMJ height. The relationships between field-based and gym-based assessments are important, as the latter offer a convenient and safe alternative in tracking athletes' physical performance. This cross-sectional study investigated the 1) relationships between the DSI and its components with CMJ height, sprinting, COD and deceleration ability, 2) possible differences between the D and ND legs during the mod505 test and 3) the possible relationships between the different supplementary COD measures in the mod505; the CODD and sub-phase analysis. The findings from this study can help to ascertain the utility of the DSI and its components as gym-based assessments that can serve as proxies for football players' sprint and COD abilities, as well as the diagnostic ability of supplementary COD measures of the mod505 like the CODD and sub-phase analysis.

For research aim 1), Hypothesis 1 was supported as there were no significant correlations between DSI and with any of the sprint and COD metrics (Table 5). This is in line with the findings from Pleša et al. (2023b), where no significant relationships were found between DSI and tra505 performance during the pre-season testing of male basketball players; with a significant moderate positive relationship found during the in-season testing. In addition to corroborating the findings from Pleša et al. (2023b) of an insignificant relationship between DSI and the 10 m sprint, there was also a lack of significant correlations between DSI and 30 m linear sprint. When looking at the components of the DSI, neither the CMJ rPF, CMJ aPF or IMTP aPF had significant relationships with the sprint and COD variables, with only a large significant negative correlation found between IMTP rPF and IAT (r = -0.54). The lack of a relationship between the CMJ force measures with sprint and COD measures was also observed in Pleša et al. (2023b), where CMJ rPF had a moderate negative relationship with tra505 performance on the left leg but not the right leg during the pre-season, with no significant relationship with 10 m sprint performance. The lack of a relationship between the IMTP peak force measures with sprint and 180° COD performance in this study, contributes to a body of work where the correlation between IMTP PF and mod505 performance varied between demographics; insignificant in male cricket academy athletes (Thomas et al., 2016), moderate (r = -0.40 to -0.44) in athletes from multiple sports (cricket, netball and basketball) (Thomas et al., 2018) and large (r = -0.57) in male collegiate athletes (Thomas et al., 2015a). The relationship between IMTP rPF and IAT was supported by Lockie et al. (2019), where it was found that IMTP rPF along with sex, 20 m sprint and left-leg lateral jump explained 84% of variance in IAT performance. Overall, it appears that DSI is not a suitable diagnostic tool for assessing sprint performances over 10 m and 30 m; as well as long and short COD performances during the pre-season. With regards to its components, the CMJ force measures appear to be inappropriate diagnostic tools as well, with the IMTP force measures having limited utility that may vary based on demographics.

In addressing research aim 2), Hypothesis 2 was supported as players were significantly faster (by 0.05s) turning on their D leg compared to their ND leg for the overall COD, CODD and S3 timing split (Table 4). This finding corroborates the work by Rouissi et al. (2016) and Clemente et al. (2022), which also found better COD performance on the D leg of football players. This finding could be related to the braking strategy of the players while turning on both legs. Deceleration before a 180° COD takes place over multiple steps as the athlete will have to reduce the velocity of his center of mass to zero (Dos Santos et al., 2019). Dos Santos et al. (2021) found that during the tra505, horizontal braking forces during the antepenultimate foot contact was more important than penultimate foot contact and final foot contact, indicating that the phase slightly before the final steps (deceleration phase) was more important in determining 180° COD performance. The current study found a large significant negative correlation between the S2-ND phase (deceleration) with COD-ND (r = -0.59) and CODD-ND (r = -0.52), while no such relationship exists for the D leg (Table 6); indicating that a shorter deceleration phase led to poorer COD performance on the ND leg. While not statistically significant, the ND leg also had a shorter S2 phase compared to the D leg, along with a significantly slower S3 phase (Table 4). One feasible explanation of these results is that on average, the players may have been less accustomed to performing the 180° COD on their ND leg, thus adopting inappropriate braking strategies with a delayed deceleration that led to a slower subsequent 180° COD and initial reacceleration, resulting in a poorer overall COD performance.

With regards to research aim 3), Hypothesis 3 was partially supported as large-to-nearly-perfect correlations were found between the S3 phase (corresponding to the 180° COD and initial reacceleration portion of the mod505), with COD (r = 0.90 for D and 0.93 for ND) and CODD (r = 0.80 for D and 0.81 for ND) (Table 6). Given that the CODD was conceptualised to isolate the COD component by largely eliminating the linear sprinting portion of COD test (Nimphius et al., 2013), this relationship coupled with an absence of a clear relationship between the CODD with the other subphases (Table 6) and the 10 m and 30 m linear sprint timings (Table 8), appear to strengthen the theoretical basis of the CODD. One surprising finding was the lack of significant relationships between COD time and majority of the sub-phases (S1, S2 and S4), whereas significant relationships were found between total COD time and all sub-phases in the original sub-phase analysis study by Ryan et al. (2021). The variation in findings can be potentially explained by a combination of factors: the differences in participant demographics (female netballers vs male football players), ground surface (netball court vs synthetic soccer pitch), footwear (court shoes vs soccer studded shoes) and faster average COD times in this study (2.36s vs 2.75s in the original study). As alluded to in the methods, the S3 phase had to be conceived by pooling together the 180° COD and initial reacceleration phases from Ryan et al. (2021), due to the inability of this timing gate setup to capture the 180° COD phase for a large portion of the players. While center of mass was not measured during this study, it is possible that the combination of factors mentioned above resulted in a COD technique with a lower center of mass that could not cleanly pass clear the last timing gates after the COD. Nonetheless, the sub-phases as conceived in this study do provide additional insights about the possible turning strategies employed during the 180° COD, as indicated in the previous paragraph.

There were limited relationships between the two COD tests: IAT and mod505, with a significant moderate correlation between IAT and COD-D (r = 0.46) and no significant correlations for the COD-ND (Table 6). These results corroborate the findings from Kozinc & Šarabon (2022), suggesting that the IAT and mod505 examine two different physical qualities, with the former assessing maneuverability and the latter assessing pure COD. In addition, strong correlations were found between the IAT with the 10 m linear sprint (r = 0.53) and 30 m linear sprint (r = 0.61), whereas only moderate correlations were found between COD-ND with 10 m linear sprint (r = 0.48) and 30 m linear sprint (r = 0.46) (Table 8). While just falling short of statistically significance (p = 0.054), the correlation between COD-D and the 10 m linear sprint (r = 0.45) was also found to be moderate (Table 8). The magnitudes of these correlations suggest that the IAT was more related to longer sprint performance while the mod505 was more related to shorter sprint performance. These findings reflect the respective sprint distances in each test, with the IAT featuring a number of CODs at smaller angles. As such, these two COD metrics: IAT and mod505 are not interchangeable and it may be worth including both tests when assessing COD ability holistically.

Lastly, out of the different gym-based assessments, CMJ-H displayed the greatest number of relationships with the different sprint and COD measures (Table 5). There was a large significant negative correlation with 10 m sprint (r = -0.51) and a very large significant negative correlation with 30 m sprint (r = -0.80). This pattern was supported by findings from Vescovi & McGuigan (2008), where the relationship between linear sprinting and CMJ-H was stronger with increased sprint distances. There were no significant correlations found between CMJ-H with overall COD and CODD timings in the mod505 for either leg but a large significant negative correlation was found with IAT (r = -0.62). One possible explanation for this is the longer duration and greater time spent linear sprinting in the IAT compared to the mod505. When looking at the sub-phases within the mod505, moderate-to-large significant correlations were found between CMJ-H with S2-D (r = -0.49), S4-D (r

= -0.56) and S4-ND (*r* = -0.46), which corresponds to the deceleration and second reacceleration phase respectively. Ryan et al. (2020) discussed the relevance of the slow stretch-shortening cycle (SSC) (> 0.25s) in a 180° COD test like the tra505 and mod505 test; the slow SSC being a hallmark neuromuscular quality of the CMJ (Van Hooren & Zolotarjova, 2017). Thus, despite the relationship being only present in the D leg, these findings offer some potential evidence of the role the slow SSC plays in the deceleration and second reacceleration phases of the mod505.

3.6 Conclusion

The main findings of this study were that DSI was not related to sprint and COD performance of professional male football players during the preseason. The players exhibited better COD performance in the mod505 turning on their dominant leg compared to their non-dominant leg. In addition, the S3 phase corresponding to the 180° COD and initial reacceleration portion of the mod505 was also related to both COD and CODD in the mod505, which strengthens the theoretical basis of the CODD. There was also a lack of a strong relationship between the two COD tests: mod505 and IAT. Lastly, CMJ-H was related to sprint performance and IAT timings, with the relationship being stronger in the longer sprint distance (30 m vs 10 m). Therefore, this thesis found that the DSI and its components had limited utility in assessing sprint and COD qualities of football players during the pre-season, with CMJ-H appearing to be a more useful metric to track. There could be value in including both shorter and longer COD tests like the mod505 and IAT for a comprehensive COD ability assessment, as they appear to assess different physical qualities. In addition, this is also the first known study using additional timing splits for a sub-phase analysis in a 180° COD test for professional football players, with the findings indicating insights into the differences in turning strategy on the dominant vs non-dominant leg.

Chapter 4: Summary and conclusions

4.1 Summary

The preliminary aim of this thesis was to examine the literature and review the different methods used to calculate the DSI as well as its link to different sport performance measures. Chapter 2 found that the lower body bilateral DSI was most commonly used form of the DSI, with the CMJ and IMTP being the most commonly used measures for measuring dynamic and isometric strength respectively largely due to their reliability. As such, these measures were selected when designing the methodology for Chapter 3. Despite the similarities in theoretical underpinnings between the DSI and COD, only one study (Pleša et al., 2023b) has directly investigated this relationship. Thus, Chapter 3 sought to build upon this limited literature.

The primary aim of this thesis was to 1) investigate the relationships between DSI and its components with CMJ-H, sprinting, COD and deceleration ability in professional football players. We hypothesized that for 1), there will be either no significant relationship between DSI and COD measures, taking reference from the findings of Pleša et al. (2023b). Hypothesis 1 was supported as there were no significant relationships found between DSI and its components with any of the COD and sprint measures. The secondary research aims were to investigate: 2) possible differences between the D and ND legs during the mod505 test and 3) the relationships between the different supplementary COD measures in the mod505; the CODD and sub-phase analysis. We hypothesized that for 2), COD performance will be better on the D leg and for 3), there will be significant relationships between CODD and some of the sub-phases of the mod505. Hypothesis 2 was supported as COD, CODD and S3 split timings were significantly faster on the D leg. Coupled with the sub-phase analysis findings, one possible explanation for this could be the different braking strategies employed when turning on the different legs, where unfamiliarity turning on the ND leg led to a shorter deceleration phase being correlated with poorer COD performance (longer COD and CODD timings). Hypothesis 3 was partially supported as large correlations were found between CODD and the S3 phase that corresponds to the 180° COD and initial reacceleration sub-phase of the mod505, strengthening the theoretical basis of the CODD.

4.2 Practical recommendations

The main practical finding of this thesis is that the DSI showed limited utility as a diagnostic tool for assessing the sprint and COD abilities of professional football players during the preseason. On the other hand, CMJ-H was related with sprint performance, COD performance in the IAT and certain sub-phases of the mod505, which potentially makes it a useful and convenient tool for monitoring the physical condition of professional soccer players over the course of a season. From a training perspective, coaches can also consider increasing the training of 180° COD ability on the ND leg. Both the sub-phase analysis and the CODD offer diagnostic value as supplementary metrics of the mod505, with the former offering greater resolution to the different phases and the latter as a convenient metric that can reduce the contribution of the linear sprinting component to overall COD performance. There could be value in including both a shorter COD test like the mod505 and a longer COD test like the IAT as they are not interchangeable measures and offer a more comprehensive COD ability assessment.

4.3 Limitations and future research

One limitation of the study is its cross-sectional nature and that it was conducted during the pre-season of professional football players. As evidenced by Pleša et al. (2023b), some relationships were found between DSI and COD measures during the in-season of male basketball players despite being non-existent during the pre-season. Nonetheless, this study reaffirmed the lack of such a relationship during the pre-season period and the study can potentially be replicated during the in-season to see if a similar trend can be found for this particular demographic of professional football players.

As mentioned in the discussion section of Chapter 3, the initial sub-phase configuration by Ryan et al. (2021) had to be modified by pooling the 180° COD and initial reacceleration phases into the S3 phase, due to the specific timing gates setup being unable to isolate the 180° COD split for a large portion of the players. While this adapted setup still offered additional diagnostic value to the mod505 test, it was unable to completely isolate the 180° COD phase. Future research can look into investigating COD technique via video analysis or 3D motion capture to determine if a more appropriate setup would be better suited for this study's demographic; taking also into account the differences in surface and footwear and how these factors may possibly impact COD technique. One potential adjustment could be to lower the timing gates height to account for the potentially lowered center of mass for this demographic when performing the COD.

Lastly, all the COD tests used in the study, the IAT and mod505 were pre-planned COD movements. While they are useful for isolating the physical component of the COD from a strength and conditioning viewpoint, a large portion of CODs that happen in the game of football are in reaction to a stimulus (agility). Thus, future research can look at incorporating tests like the reactive agility test for more comprehensive profiling of players' overall COD ability (Sheppard & Young, 2006).

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Appendix A- Consent Form

Project title: ***The relationships between the dynamic strength index with deceleration and change of direction ability in athletes***

Project Supervisors: ***Dr. Adam Storey, Dr Marcus Lee***

Researcher: ***Tan Jian Zhi Kenny***

○ I have read and understood the information provided about this research project in the Participant Information Sheet

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

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

○ I understand what the research entails: a single testing session involving maximal-effort countermovement jumps, isometric mid-thigh pulls, 30 m sprints, Illinois Agility Tests and modified 505 agility tests.

○ I understand that if I withdraw from the study then I will be offered the choice between having any data that is identifiable as belonging to me removed or allowing it to continue to be used. However, once the findings have been produced, removal of my data may not be possible.

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

○ I meet all of the eligibility criteria as set out in the Participant Information Sheet: 1) an active, well-trained male or female athlete in Singapore (aged 18-35 years), 2) have no history of lower body injury in the past 6 weeks, 3) are not a student of, or athlete directly working with any of the named researchers and 4) are in a land-based sport that has a change of direction element.

*well-trained refers to currently engaging in structured sport training ≥2x a week and has competed in official competitions.

○ I agree to provide information related to my performance testing data.

○ I agree to take part in this research.

○ I wish to receive a summary of the research findings (please tick one): Yes○ No○

○ I would like to receive a copy of my individual results (please tick one): Yes○ No○

Participant's signature: ....

Participant's name: ....

Participant's Contact Details (if appropriate):

………………………………………………………………………………………..

Date: _______/______/_________

Approved by the Auckland University of Technology Ethics Committee on 18/9/2023 granted AUTEC Reference number 23/251. *Note: The Participant should retain a copy of this form.*

Appendix B- Participant Information Sheet

Date Information Sheet Produced:

22/11/2023

Project Title

The relationships between the dynamic strength index with deceleration and change of direction ability in athletes.

An Invitation

Hi, my name is Kenny Tan, and I am currently a Masters student at the Auckland University of Technology (AUT), New Zealand and a Sport Scientist with 3 years of experience working with athletes. I am inviting you to participate in the above-named study which is a research-based investigation conducted by myself and supervised by Dr Adam Storey from AUT and Dr Marcus Lee from the Singapore Sport Institute. Your participation, or lack of participation, is completely voluntary. Your consent to participate in this research study will be indicated by you signing and dating the consent form. Signing the consent form indicates that you have read and understood this information sheet, freely given your consent to participate, and that there has been no coercion or inducement to participate by the researchers from AUT. The results of this research are intended for publication and will contribute to my Master's degree and may be submitted to peer-reviewed journals for publication.

What is the purpose of this research?

Change of direction (COD) and deceleration are important aspects in many sports. The need to make constant movement adjustments during gameplay and the repeated high braking forces involved can damage muscles and impair your ability to produce force. The Dynamic Strength Index (DSI) is an assessment of your ability to produce force dynamically in comparison to your total maximal strength capability and can be useful in helping to design a training program to suit your individual needs. A low DSI ratio (≤0.60) indicates that you will require more ballistic 'explosive' strength training and a high DSI ratio (≥0.80) would indicate the need for more maximal strength training. The primary aim of this investigation is to investigate if your dynamic strength index (DSI) is related to your COD and deceleration abilities in the Illinois Agility Test and modified 505 agility tests. The secondary aim is to determine if there is a relationship between your COD and deceleration abilities in the Illinois Agility Test and modified 505 (mod505) agility tests. The results of this investigation will assess the effectiveness of using the DSI as a diagnostic tool for COD and deceleration ability in team sport athletes, to inform future training practices.

As previously mentioned, this research is in fulfilment of my Masters of Sport, Exercise and Health at the Auckland University of Technology, and the information gathered in this study may be used for articles submitted for publication.

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

You have seen a physical flyer in the Singapore Sport Institute or received a virtual flyer through your coach from the primary researcher Kenny Tan and contacted him, Dr Marcus Lee or Dr Adam Storey via email to indicate interest in this research. As this study is looking to identify the association between DSI and COD variables mentioned above in well-trained athletes, you have been identified and invited to participate in this research. Your participation in this study would help to further our knowledge of this area. You are eligible to participate in this study if you are 1) an active, well-trained* male or female athlete in Singapore (aged 18-35 years), 2) have no history of lower body injury in the past 6 weeks, 3) are not a student of, or athlete directly working with any of the named researchers and 4) are in a land-based sport that has a change of direction element.

*well-trained refers to currently engaging in structured sport training ≥2x a week and has competed in official competitions.

How do I agree to participate in this research?

If you agree to participate in this research study, you will be required to complete a Participant Consent Form which can be obtained from Kenny Tan, Dr Marcus Lee or Dr Adam Storey. You are able to withdraw from the study at any time. If you choose to withdraw from the study, then you will be offered the choice between having any data that is identifiable as belonging to you removed or allowing it to continue to be used. However, once the findings have been produced, removal of your data may not be possible.

What will happen in this research?

Once you have decided to participate in the study and have met the inclusion criteria, you will report to the Singapore Sport Institute or the designated training facility of your National Sport Association for one test session and go through a standardised dynamic full-body warm up before the session: a 5 min jog at a moderate pace, followed by 10 repetitions of bodyweight squats and 10 repetitions of bodyweight lunges on each leg. Your height, weight, age range and position will be collected. There are three components within each session: 1) DSI, 2) mod505 test with 30 m linear sprint and 3) Illinois Agility test. You will first undergo 1), followed by 2) and 3) with at least 5 min of rest between each component:

DSI

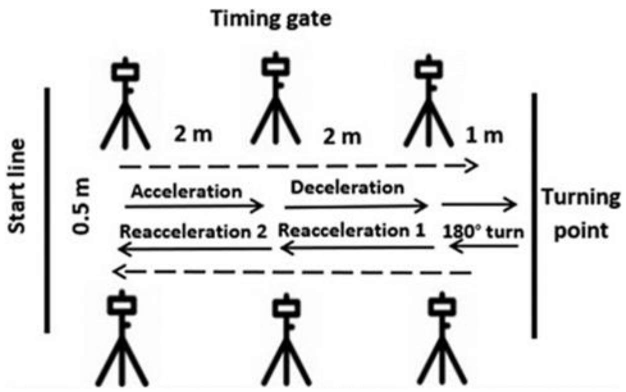
You will perform 2 maximal-effort countermovement jumps (CMJ) trials followed by 2 maximal-effort isometric mid-thigh pull (IMTP) trials with 5 min rest between the two tests and 2 min rest between the trials within each test.

Mod505 test with 30 m linear sprint

You will perform 2 trials of the 30 m linear sprint and 4 trials (2 trials turning on each leg in a randomised sequence) of the mod505 test using the timing gate set-up in Figure 1. Both tests will have 5 min of rest between trials. In the linear sprint, you will start behind the start line and conduct a maximal sprint past the 30 m line. In the mod505 test, you will sprint from the start line to the turning point, perform a 180 ° COD and sprint back past the start line.

Figure 2

Sub-phase analysis of Modified 505 test (Ryan et al., 2022)

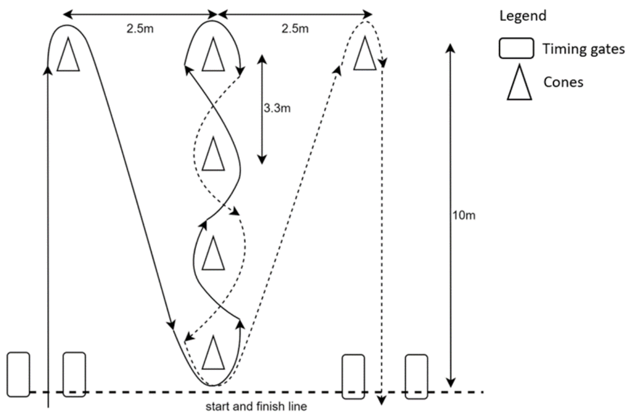


Illinois Agility Test (IAT)

You will perform 2 trials of the IAT using the timing gate set-up in Figure 2. You will sprint from the start line, perform the series of sprints and CODs as indicated in the figure and sprint back past the start line. There will be 5 min of rest between trials.

Figure 2

Illinois Agility Test (IAT)



What are the discomforts and risks?

You will be asked to perform maximal effort isometric, jump and change of direction movements during the testing session and therefore may experience some discomfort for a short period of time during the session or for some hours thereafter. However, the intensity of the sessions will be similar to what you have experienced in your typical strength and conditioning training sessions.

How will these discomforts and risks be alleviated?

Being a trained athlete who regularly performs high-intensity resistance exercise, you will be very familiar with the high intensities efforts that are required during the testing session. If you are experiencing discomfort at any stage during the testing session you are encouraged to immediately inform the researcher supervising the session to best address the problem.

If you have any questions regarding the risk or discomfort that you anticipate, please feel free to address these concerns to the researcher so that you always feel comfortable throughout the process.

What are the benefits?

Participants will gain a personalised profile which will contain their DSI, CMJ peak force, IMTP peak force, IAT and mod505 timings. New knowledge for researchers and practitioners will be gained as we look to explore the potential relationship between DSI and the different measures of COD in the IAT and mod505 tests. The wider professional sporting community will benefit by learning more about the suitability of DSI as a diagnostic tool to assess COD ability in athletes. The results of this research are intended to be used in my Master's thesis and may be submitted to peer-reviewed journals for publication.

What compensation is available for injury or negligence?

In the unlikely event of a physical injury as a result of your participation in this study, rehabilitation and compensation for injury by accident may be available from the Acclaim Insurance Brokers Pte Ltd, providing the incident details satisfy the requirements of the law and the organisation's regulations. In addition, medical treatment of physical injuries occurring directly as a result of the study is available at the Sport Medicine Centre within SSI, with the degree of medical cost coverage varying on a case-to-case basis.

How will my privacy be protected?

Your privacy will be protected at all times by the data being de-identified (i.e., coded numbers such as I.D 432 will be assigned to your data instead of your name), and the researcher will not disclose any participants involvement in this study. No names will be used in reporting unless the participant gives written consent following the AUT protocols. During the research study, only the applicant and named researchers will have access to the data collected. The results of the study may be used for further analysis and submitted to peer-viewed journals or submitted to conferences. However, only the group averages of the descriptive characteristics (i.e., height, weight etc.) will be published, and thus, the participants will not be identifiable from the publications related to this study. Your privacy and confidentiality will be upheld as the primary concern when handling the data collected.

All data collected will be stored on password protected computers or in securely locked files. Following completion of the data analysis process your data will be stored by the AUT University SPRINZ research officer in the AUT University SPRINZ secure Ethics and Data facility at the AUT Millennium campus for six years. Following the six-year storage period all hard copies of data will be destroyed (shredded) and electronic data will be deleted.

What are the costs of participating in this research?

There will be no financial cost for you being involved with this study, aside from travel costs to and from the Singapore Sport Institute or the designated training facility of your National Sport Association. You will be required to commit approximately 2 hours total towards a single testing session.

What opportunity do I have to consider this invitation?

It will be appreciated if you could let us know within two weeks whether you would like to or be available to take part in the study or not. After consideration you may withdraw your participation at any time.

Will I receive feedback on the results of this research?

Yes, participants will gain a personalised profile which will contain their DSI, CMJ peak force, IMTP peak force, IAT and mod505 timings. It is your choice whether you share this information with other people. You will also receive (if you wish), a summary of the research findings. You may also inform the primary researcher if you do not wish to receive this personalised profile.

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

Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisors, Dr. Adam Storey, adam.storey@aut.ac.nz, +64212124200 or Dr Marcus Lee, marcus_lee@sport.gov.sg, +6565005339.

Concerns regarding the conduct of the research should be notified to the Executive Secretary of AUTEC, ethics@aut.ac.nz, (+649) 921 9999 ext 6038.

Whom do I contact for further information about this research?

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

Researcher Contact Details:

Kenny Tan

AUT-Millennium, 17 Antares Place, Mairangi Bay

+6583388256

tcz4998@autuni.ac.nz

Project Supervisors Contact Details:

Dr. Adam Storey

AUT-Millennium, 17 Antares Place, Mairangi Bay

+64212124200

adam.storey@aut.ac.nz

Dr Marcus Lee

Singapore Sport Institute, 3 Stadium Drive, Singapore 397630

+6565005339

marcus_lee@sport.gov.sg

Approved by the Auckland University of Technology Ethics Committee on *22/11/2023*, AUTEC Reference number *23/251*.