Sport specialisation, movement competency and injury in New Zealand youth football players.

Anja Carina Zoellner

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Sports Performance Research Institute New Zealand, Auckland University of Technology

Primary Supervisor: Associate Professor Chris Whatman

Secondary Supervisor: Associate Professor Paul Read

Tertiary Supervisor: Dr Kelly Sheerin

Abstract

Sport specialisation is defined as year-round, intentional participation in a single sport, to the exclusion of other sport, and it is a topic of ongoing debate in youth sport. While some believe specialising at a young age is important for future sporting success, there is little evidence to support this. Long-term outcomes for specialised young athletes are still unknown, but there has been some suggestion it may limit movement development, and this may be associated with increased risk of injury. Anecdotally, youth football in New Zealand (NZ) has a high prevalence of specialisation, and an increase in youth sport injuries in NZ has been reported. Therefore, the aim of this research was to investigate the association between sport specialisation and movement competency in youth football players in NZ.

A review of the literature was completed (Chapter 2), to investigate the evidence for an association between sport specialisation and movement competency in youth sport. Results suggested that jump landing strategies may differ in specialised youth compared to their non-specialised counterparts. However, inconsistencies in the definitions and methods used to define and measure both specialisation and movement competency were highlighted, as was the need for sport specific research.

A nationwide survey of youth football players was then conducted to determine the prevalence of specialisation in NZ, and whether there were associations between the level of specialisation and 12-month injury history (Chapter 3). Forty-three percent of 10–15-year-old football players were classified as highly specialised and a high proportion (84%) of participants reported injuries in the past 12 months. While no difference was observed in the odds of reporting an acute injury, highly specialised players were four times more likely to report a gradual onset injury than low and moderately specialised players, when the volume of sport participation was controlled for.

Three cross-sectional studies were subsequently conducted (Chapters 4, 5 and 6). First, an investigation of early specialisation and its association with movement competency in pre peak height velocity (PHV) football players, categorised into high, moderate, or low specialisation groups (Chapter 4). Drop jump landings were compared using the landing error scoring system and dynamic balance was analysed using the Y-balance test. Highly

specialised players demonstrated superior landing mechanics (less technique errors) and better relative reach distances in the Y-balance test.

The association between football development pathway and movement competency in a cohort of post-PHV players was investigated in Chapter 5. Movement competency was assessed using a single-leg countermovement jump, drop jump and Y-balance test. Players were grouped based on their history of participation as having undertaken a specialised or diverse (i.e., not specialised) pathway. Results were analysed based on group (specialised or diverse) and the number of years players had been specialised. No differences between specialised and diverse groups were found; however, small improvements in reactive strength index, jump height, and the number of landing errors were seen with an increase in the time specialised.

The final cross-sectional study investigated the association between sprint and change of direction (COD) performance and development pathway in post-PHV footballers (Chapter 6). Specialised players exhibited greater COD asymmetries and sprint kinetic outcomes, and COD kinematic strategies associated with faster, but more risky task completion strategies than diverse players.

Cumulatively, the results from this thesis suggest a high prevalence of specialisation in youth football in NZ, and that specialisation is associated with a history of overuse injury. Some strategies displayed by specialised players suggested improved movement competency and increased efficiency; however, some of these strategies are associated with increased injury risk. While there may be some improvement in movement outcomes in specialised players, the strategies used to achieve these outcomes need further investigation, including longitudinal research.

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List of Common Abbreviations

CI	confidence intervals
COD	change of direction
CODD	change of direction deficit
DJ	drop jump
ES	effect size
FMS	functional movement screen
LESS	landing error scoring system
NZ	New Zealand
PHV	peak height velocity
SD	standard deviation
SLCMJ	single leg countermovement jump

Attestation of authorship

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

Anja Zoellner

Co-authored works

Peer-reviewed journal publications

Manuscripts published

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

Anja Zoellner

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Associate Professor Paul Read

Dr Kelly Sheerin

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Ethics approval

Ethical approval was granted by the Auckland University of Technology Ethics Committee (AUTEC) for the research conducted as part of this thesis on:

- 26 April 2018 AUTEC reference number 18/158 (Chapter 3; Appendix A)
- 15 May 2020 AUTEC reference number 20/45 (Chapter 4; Appendix B)
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Chapter 1 Introduction

1.1 Background

1.1.1 Defining the issue

Football (soccer) is one of the most popular sports globally and within New Zealand (NZ). NZ Football reported 30 to 50% growth in junior and youth football participation between 2011 and 2016 (New Zealand Football, 2016a) and it remains one of the most popular youth team sports in the country (Sport NZ, 2021). Increased participation promotes competition for positions within teams and academies and potentially the prevalence of sport specialisation. Sport specialisation has been defined as year-round, focussed participation in a single sport (Bell et al., 2021). Proposed reasons for specialisation include attempts to elevate chances of scholarships, sponsorships, or future success (Bergeron et al., 2015). The potential long-term implications of this focused, single sport approach remain largely unknown and are likely to be sport specific. To better inform coaches, players, and parents, sport specific research is needed to identify outcomes, both positive and negative, associated with sports specialisation.

Position statements from several organisations, including the International Olympic Committee (Bergeron et al., 2015) and the American Medical Society for Sports Medicine (DiFiori et al., 2014), acknowledge the possibility of negative outcomes following sport specialisation in youth, and advise against specialising before adolescence. Potential negative outcomes include burn out, social isolation, drop out, and increased injury risk (Brenner, 2007). Increased injury risk is, in part, thought to be due to the greater volume, and exposure of sport participation in specialised youth (DiFiori et al., 2014; Read et al., 2016c). Of particular concern is a reported increase in chronic/overuse injuries in those who are specialising in a single sport at a young age (McGowan et al., 2020). These injuries may be due to greater training and competition loads and a narrow range of repeated movement patterns (Read et al., 2016c). This means injuries, and any potential movements influenced, are likely to be specific to the sport and the movement patterns commonly used and repeated in these sports. However, evidence to date has mostly come from studies which have been cross-sectional (thus not designed to show causality), and many do not control for volume or exposure, factors known to modify injury risk. Additionally, many studies have included young athletes from multiple different sports which may have a confounding effect (Jayanthi et al., 2015; McGuine et al., 2017; Pasulka et al., 2017; Post et al., 2017a). Given the context of individual sports differs in different locations, regionally and internationally, based on factors including popularity and economy, the youth sporting context will also differ. For example, in the United Kingdom, football is a high participation, high investment sport, with academies recruiting talented players from young ages. In contrast, NZ has high participation and low investment, with limited pathways to elite performance. Therefore, more sport (and context) specific research is needed into how specialisation may influence long term development, as well as potential mechanisms behind the increase in injuries seen in youth who are specialising.

NZ football is comprised of seven federations (regions) throughout the country. Individual clubs belong to federations and play in competitions within their federation. Pathways for youth to reach the national or international levels start at clubs, working through to premier age group teams. Federations will also select players in age groups to participate in training camps and national tournaments or leagues. Youth national teams are fielded from under 17 through to under 20. Youth academies have varying structures depending on funding, but typically do not include specific strength and conditioning training. As a result, most youth footballers are unlikely to be exposed to structured strength and conditioning training unless this is driven by themselves or their parents.

1.1.2 Defining sport specialisation

Sport specialisation is defined as "intentional and focused participation in a single sport for the majority of a year that restricts opportunities for engagement in other sports and activities" (Bell et al., 2021). However, there is no consensus in the classification method, making it difficult to compare the results of different studies. Before the publication of the consensus definition in 2021, which is the most recent definition, the most frequently cited definition was that of Jayanthi and colleagues stating that sport specialisation was the intense, year-round involvement in a single sport to the exclusion of all other sport (Jayanthi et al., 2015). Classification methods in research prior to 2021 are shown in Figure 1.1 and were based on aspects of this definition and dichotomous, either specialised or not, or based on a three-point or six-point scale which classifies youth as high, moderate, or low specialised (Jayanthi et al., 2015).

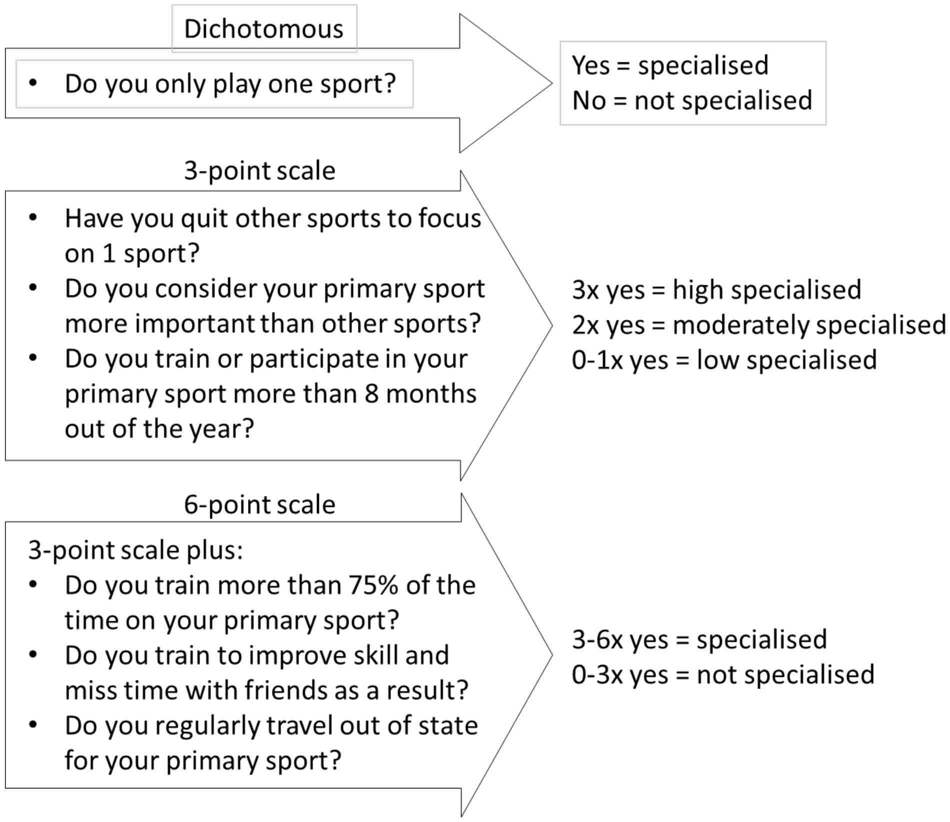

Figure 1.1: Scales used to classify level of specialisation

Based on Jayanthi et al. (2015) definition of sport specialisation, the four main considerations are intensity, year-round involvement, single sport, and the exclusion of all other sports (Jayanthi et al., 2015). Early classifications were dichotomous, either specialised (single sport) or not (multi-sport) (Hill & Simons, 1989). However, this method only addresses the single sport and exclusion of all other sports components of the definition, and it was suggested that youth might be better classified along a continuum (Jayanthi et al., 2013). Three and 6-point scales were subsequently introduced (Jayanthi et al., 2015). The 3-point scale was deemed to be more appropriate as it addressed year-round involvement, while the 6-point scale attempts to gain more detail, by adding three questions that focused on the intensity and level of play. Arguably, the three additional questions in the 6-point scale give greater insight into how the primary sport affects the overall life of the athlete, but also add another level of complexity and potential error, particularly when considering younger populations. These might be contributing reasons for this scale not being widely adopted by the research community. Interestingly, while the 3-point scale allows athletes to be categorised as high, moderate, or low specialised, the 6-point scale has a dichotomous outcome of 'specialised' (4-6 'yes') or 'not specialised' (0-3 'yes'), which potentially increases the variation in the participation of 'specialised' athletes.

The dichotomous outcome of either 'specialised' or 'not specialised' does have some advantage in terms of ease of grouping and coaching recommendations in practice. For example, recommendations for specialised players and recommendations for players who are not specialised. Recommendations for moderately specialised players may be more difficult for coaches in practice. However, there may be a need for a change in questions used to classify players, to ensure correct classification based on what players are doing in practice, given they still do not get an accurate estimate of intensity, which begs the question of whether the 6-point scale adds anything on top of the 3-point scale. Unfortunately, there is a lack of consistency in current research, and little evidence to report their reliability and/or validity, with limitations present in each of these methods.

Another common classification method is the simple dichotomous 'single-' or 'multi-sport' method involving youth classifying themselves solely based on the number of sports they play. However, this relies on self-classification and does not address the intensity or amount of time throughout the year that youth are participating in these sports, nor whether they have given up other sports. The 3- and 6-point scales better address all components in the definition of specialisation suggesting they might be more valid, however none of these methods have been validated. The 3-point scale seems to be the most frequently used method, and encompasses most of the specialisation definition except for intensity, which is likely a contributing factor to any long-term outcomes of specialisation (Jayanthi et al., 2015). The volume of participation should also be considered and may have associations with an increased risk of overuse injury. A broad measure of this is included in the 3-point scale, where athletes are asked if they participate in their main sport for 8 months or more of the year; however, this does not provide any detail on weekly participation volume or intensity, and as such this may need to be assessed separately. The development of a consensus definition in 2021 will be beneficial in improve consistency in sport specialisation research moving forward. However, while this is a comprehensive definition, it does not include any recommendation on improved methods of classification that could be adopted in future research.

To achieve elite-level sport performance some level of specialisation is likely needed (McKay et al., 2019); however, there is debate around what age is appropriate for this to occur. Numerous studies suggest that 'early' specialisation (specialising at a young age) could have negative long-term consequences in young athletes (Malina, 2010; Myer et al., 2015; Pasulka et al., 2017; Wall & Côté, 2007). However, there does not appear to be any consensus on the age at which specialisation is considered 'early'. Some studies suggest specialisation before age 12 is considered 'early' (Côté & Hancock, 2014; Merkel, 2013), others have proposed before 16 years (DiFiori et al., 2018), or before 'complete physical maturation' (Brenner & Council On Sports Medicine and Fitness, 2016; DiFiori et al., 2014). The answer is likely to depend on the demands of each sport, as well as the age at which peak performance typically occurs. In some sports, such as gymnastics, peak performance occurs prior to full physical maturation, and smaller stature and mass is beneficial to performance, resulting in specialisation occurring at a younger age (Kliethermes et al., 2020). Youth athletes from sports where peak performance occurs after physical maturation may benefit from diverse exposure to movements and sports throughout adolescence (Brenner & Council On Sports Medicine and Fitness, 2016; LaPrade et al., 2016). Additionally, evidence suggests that elite level adult athletes are more likely to have followed a diverse sporting pathway before specialising in late adolescence (Hornig et al., 2016; Jayanthi et al., 2013; Vaeyens et al., 2009).

1.1.3 Outcomes of sport specialisation

Sport specialisation in youth athletes has been linked with negative social and psychological outcomes as well as burn out, drop out and increased injury risk (Jayanthi et al., 2013; Moesch et al., 2011; Wall & Côté, 2007). Additionally, specialisation is thought to negatively affect movement skill development in youth athletes due to repetitive training of the same movements (Atkins et al., 2016; Trecroci et al., 2019). The evidence on the effects of specialisation is limited by the methodologies used, and while associations have been found in some studies, most were cross-sectional and/or retrospective, and not designed to show causation. Nevertheless, in the interests of protecting youth athletes, maximising development and enjoyment, minimising injuries, and optimising long-term outcomes, more research in this area is warranted. It has been suggested that youth players who follow a non-specialised, more diversified sporting pathway (e.g., playing football as well as a range of other sports) may benefit from the greater variety of training and develop enhanced movement competency (Fransen et al., 2012). Optimal movement development has been suggested to include motor skill competencies as well as muscular strength and an ability to control forces acting on the body, as proposed by the athletic motor skills competencies framework (Radnor et al., 2020).

Sport specialisation often coincides with adolescence, a time when youth undergo periods of rapid growth, changes in body composition and strength, and periods of altered neuromuscular control, often referred to as 'adolescent awkwardness'. This is a temporary period of decreased motor skill performance coinciding with rapid growth (Philippaerts et al., 2006). Evidence indicates adolescent youth are at an increased risk of injury during these periods (Read et al., 2018c; van der Sluis et al., 2014). A large volume of repetitive movements performed at high intensities often associated with sport specialisation places already vulnerable structures under increased stress and can contribute to injuries such as Sever's, Osgood-Schlatter, and Sinding-Larsen-Johansson syndromes (Baker et al., 2009; DiFiori et al., 2014; McKay et al., 2019). The incidence of each of these growth injuries is higher at specific stages of growth and development (DiFiori et al., 2014; McKay et al., 2019; McKay et al., 2016).

Childhood and adolescence are periods of high neuroplasticity. This is an optimal time to develop broad movement skills and build a foundation from which technical, sport specific skills can be optimised (Myer et al., 2011; Myer et al., 2013; Read et al., 2016c). Early engagement in a variety of sporting and athletic activities is important to develop athletic motor skill competencies and maximise these benefits (Myer et al., 2011; Myer et al., 2013; Radnor et al., 2020; Read et al., 2016c). Sport specialisation in youth has been associated with altered movement development, potentially due to intensive sport specific training, with reduced exposure to more generalised tasks (Jayanthi et al., 2015). This could limit movement development and predispose young athletes to increased injury risk (Atkins et al., 2016; Hall et al., 2015). Youth who follow a diversified pathway may be exposed to a broader range of movement patterns, giving them the opportunity to develop a greater range of movement skills, through more varied sporting involvement. This range of movement competencies can have beneficial effects later in life, both for injury prevention and maintaining sport involvement (DiStefano et al., 2018; Radnor et al., 2020). Additionally, sport specialised youth complete greater volumes of training and competition and thus are predisposed to increased risk of injury (McGuine et al., 2017; Myer et al., 2016). This has previously been reported in baseball players (Olsen et al., 2006), but there is a lack of evidence from other sports to examine associations between the level of specialisation and intensity of competition.

Much of the existing research focuses on the negative effects of early specialisation, yet there are potential benefits. Reasons cited for choosing to specialise are predominantly to increase chances of future sporting success, whether this be scholarships, selections for teams, or academies (Post et al., 2019). This is not entirely without merit as involvement in an academy system has been reported to increase chances of future selection (Huijgen et al., 2014). Conversely, once deselected, chances of re-selection drops (Huijgen et al., 2014). This could be due to familiarity with coaches and/or selectors, however, there is likely also some association with performance. Deselected youth are less likely to have access to the same high level of coaching, equipment, or facilities, and are more likely to drop out, and experience negative psychological outcomes (Huijgen et al., 2014; Sweeney et al., 2021). In some contexts, these youth may have no access to any sporting/training facilities or coaching, leading to slower development of skill, strength, and neuromuscular control. Conversely, youth who specialise and/or participate in higher level teams and academies receive access to higher level coaching, better equipment, facilities, and greater exposure to competitive game environments (Waldron et al., 2014). Good coaches in well-resourced academies or clubs may structure a program to include variety, even if the youth are only playing one sport (Jayanthi et al., 2022). This could include access to effective strength and conditioning, or the inclusion of other sports within training, either as a warmup activity or on recovery days (Mosher et al., 2022).

An additional factor to consider is access to trained coaches. The argument that quality coaching can provide varied training and appropriate strength and conditioning regardless of other sport participation assumes young athletes from all sports, specialised and not, have access to facilities and guidance (coaching) to help them develop broad movement skills. This is not necessarily the case, with some countries and sports likely only having access to appropriate/any strength and conditioning, neuromuscular training guidance at high levels and/or older age groups. In these cases, taking a specialised route may be the best way to get exposure to these types of training at a young age.

Performance in task-specific outcomes may also be improved with specialisation, due to the focused nature of training. To our knowledge, there is no existing evidence on differences in strategy used for sporting movements based on level of specialisation. However, with potential alterations in movement patterns and increased training exposures in more specialised players, it could reasonably be expected that an athlete's ability to produce force would also be affected. This is supported by Gissis et al. (2006) who reported differences in isometric knee extensor force-time characteristics between elite, sub-elite, and recreational youth football players. There are many differences between isometric force production ability in a single joint and multi-joint, dynamic force production. However, players who have greater training exposure, such as high specialised players, are likely to complete more sport-specific movements, and thus could display improved force production in these activities. Changes in force-velocity profile are also likely to affect several football-specific performance factors, including sprinting, jumping, and change of direction (COD) ability. Higher specialised players could demonstrate more effective technical execution of COD tasks compared to lower specialised players. It has been suggested that COD execution may be related to increased training and potentially improved performance in cutting tasks (Condello et al., 2016), COD, and sprint times (Gissis et al., 2006; Trecroci et al., 2019) in elite vs sub-elite players.

1.1.4 Movement competency

A key concern with youth specialising in a single sport is that it may limit exposure to a wider variety of movement demands (DiStefano et al., 2018; Myer et al., 2015). Movement competency is a broad term, with no standardised definition. Even within the sporting context there are a range of definitions used; however, for the purposes of this thesis, movement competency was defined as the ability to successfully perform a range of physical activities or foundational motor skills, without displaying functional deficits (Bisi et al., 2017; Dobbs et al., 2021; Robinson et al., 2015). While there is no consensus definition, developing adequate movement competency is important, not only for sports performance and reductions in injury risk, but also for long-term physical activity involvement, health, and quality of life.

There are a variety of methods proposed for assessing movement competency, depending on the context and definition. These range from measuring outputs (e.g., how many, how high, how fast), to assessing the technique or strategy used to achieve these outcomes. Variation across the research makes it difficult to compare studies and different sports. These inconsistencies also make it difficult to determine the effects that specific interventions, training, and sport exposures might have on the development of movement competency. One common assessment of movement is the functional movement screen (FMS). Due to the static nature of the tasks involved in this screen a lack ecological validity has been suggested given movements involved in football are rarely performed whilst static (Schneider et al., 2019).

The effects sport specialisation might have on movement competency in youth athletes are likely very specific to the types of movement patterns commonly used in any given sport. This highlights the need for sport-specific research, to determine how differences in training and competition exposure might affect youth athletes who chose to specialise. Tests used for assessing movement competency should be selected based on the types of movement occurring within the sport, the competencies required for these movements to be performed effectively, efficiently, and safely, and the changes expected as a result of specialisation. Potential differences in those who are exposed to high volumes of training and competition in football might include increased lower extremity asymmetry (Miller et al., 2017), elevated movement control, improved balance (Paillard et al., 2006), heightened COD and deceleration abilities (Dos'Santos et al., 2021), and changes in force-velocity profiles (Buchheit et al., 2014). This means that tests assessing differences in movement patterns between specialised and diversified (lower specialised) players need to be selected to assess these changes. In football, a combination of unilateral and bilateral tests may be most applicable, due to the unpredictability of players' movement patterns (Bishop et al., 2017). Additionally, due to the dynamic nature of football, the validity of static tests such as the FMS have recently been questioned in football players (Schneider et al., 2019). A range of other movement tests have also been proposed in youth football including a combination of the Y-balance or star excursion tests which, while predominantly static, give a measure of unilateral dynamic stability, and dynamic tests. These could include jump tests (unilateral and bilateral), and agility tests (Bishop et al., 2017; Miller et al., 2017; Read et al., 2019).

In addition to movement control, asymmetries are likely more prevalent in highly specialised football players than in low specialised players. Asymmetries would be expected to be seen in all players to some extent, due to the nature of the sport, with most having favoured kicking and stance legs (Fousekis et al., 2010). These differences are likely exacerbated by specialising in a specific position, where there may be less need to kick with one leg based on position on the field. Additionally, due to the increased training and game exposure seen in highly specialised football players, it could be expected that these differences are exacerbated. Asymmetries in strength and balance have been reported in football players as young as 9–13 years (Schneider et al., 2019) and while there is some degree of adaptation that is beneficial to sport-specific performance, asymmetries have been linked with increases in injury risk (Atkins et al., 2016; Read et al., 2018c), as well as decreased physical performance (Bailey et al., 2013; Bell et al., 2016).

1.1.5 Performance outcomes

One of the most commonly cited reasons for specialising in a single sport is to improve future performance (Post et al., 2019). However, when describing movement 'performance', it can encompass many intrinsic factors which interact and depend on any number of external contributors. In the context of sport, performance can be broken down into three main types: career performance, task performance, and sport-specific performance. Career performance refers to future career outcomes, such as selection for specific teams, scholarships, or winning championships. Task performance refers to outcomes in specific activities such as sprints, COD and balance. Sport-specific performance refers to skills required for the sport in question, such as dribbling a ball, passing, or shooting in football. In the context of sport specialisation, most performance research has been on career performance and task performance, and to this point, the majority of the evidence suggests sport specialisation does not lead to improved performance (Kliethermes et al., 2020). However, most of this research is cross-sectional or retrospective in nature and there is a need for more longitudinal research to further explore this relationship.

1.2 Purpose of the research

The main question of this thesis was what is the association between sport specialisation (including early specialisation) and movement competency in youth football players? This was achieved by answering the following sub-questions:

1. What is the prevalence of sport specialisation in NZ youth football, and is this related to injury history?
2. What is the evidence for an association between sport specialisation and movement competency in youth sport?
3. What is the association between early specialisation and movement competency in pre-PHV youth football players?
4. What is the association between football development pathways and movement competency in youth football players?
5. What is the association of sprint and COD performance with development pathways in youth football players?

1.3 Significance of the thesis

Participation in football is understood to be beneficial to the health of players of all ages, having positive effects on fitness, body image and social well-being (Moseid et al., 2018; Myer et al., 2016). However, it has been suggested that engaging in a sport specialisation pathway may not maximise these benefits in youth players. Position statements from both International Olympics Committee (Bergeron et al., 2015) and the American Medical Society for Sports Medicine (DiFiori et al., 2014) acknowledge the possibility of negative outcomes following early specialisation, and advise against specialising in a single sport before adolescence due to reported increased risk of adverse effects.

While evidence exists that exposure to movement is associated with the development of competency in those movements (Lloyd et al., 2015a; Myer et al., 2013), there is limited evidence on sport-specific adaptations to movement patterns. This has consequences for long-term motor skill development or 'task performance' and potential associations with increased injury risk. Research is needed with specialised youth from a single sport as previous studies have included youth from a range of sports. Furthermore, research on players competing in NZ is in its infancy. Due to the growing popularity of football in this country, the evidence provided in the current thesis can be used to help inform recommendations for youth sport development both in NZ and internationally.

1.4 Structure of the thesis

This thesis followed a pathway two format whereby each chapter, other than the introduction (Chapter 1) and the discussion (Chapter 7), is formatted as a manuscript for publication in a journal. Some of these have either been published already or submitted to a journal, therefore formatting may vary slightly between chapters based on the required formatting for individual journals. Due to the nature of this structure, there may be some repetition between thesis chapters, although attempts have been made to minimise this where possible.

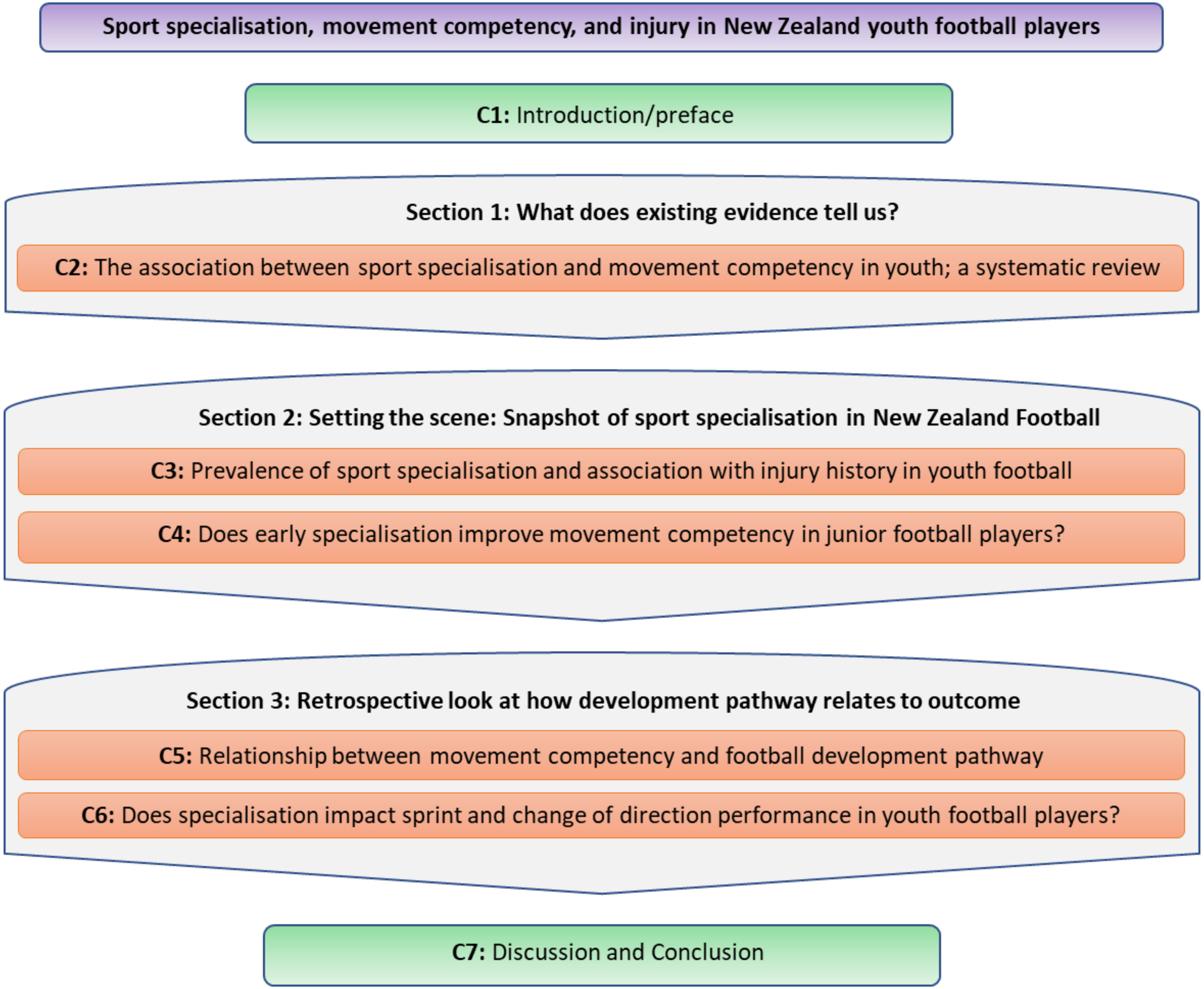

Figure 1.2: Thesis overview

The thesis has been divided into three sections, outlined in Figure 1.2. Section 1 is a literature review (Chapter 2) evaluating the existing evidence for a relationship between sport specialisation and movement competency. Section 2 is a snapshot of sport specialisation in NZ youth football which was captured in a survey investigating the prevalence of specialisation and how it relates to injury history (Chapter 3). This is followed by a cross-sectional study (Chapter 4) looking at young football players who are just starting to specialise at various levels (low, moderate, and high), and whether any differences in movement competency exist. Section 3 looks retrospectively at the pathway (specialised versus diversified) high level youth football players took to get to where they are and whether there is any association between pathway and movement outcomes. This includes a chapter focused on movement competency (Chapter 5) and a chapter focused on task-specific performance outcomes (Chapter 6). This is followed by a general discussion, specific limitations, and conclusions (Chapter 7).

1.5 Student context and challenges

This research was inspired through a combined love of football and interest in sport biomechanics and injury prevention based on a background of sporting achievement, cut short by injury. Following conversations with NZ Football, who raised concerns of anecdotally increasing rates of specialisation (and overuse injuries) in their youth football players, the studies in this thesis were developed. The underlying interests were in helping address the issues NZ Football had raised, as well as wanting to ensure a positive sporting experience and development for youth players.

The undertaking of this research was complicated by the Covid-19 pandemic, which prevented the ability to collect longitudinal data, restricted recruitment, and the generalisability of the findings given the seasons were severely impacted by Covid-19 restrictions. Chapter 4 was initially planned as a prospective study to examine changes in movement competency throughout a season, while monitoring volume and intensity of football participation. This unfortunately coincided with the Covid-19 pandemic reaching NZ. The associated restrictions resulted in interruptions to the season and the planned data collection. Ultimately the decision was made to use the data already collected and present it as a cross-sectional study. Another significant impact on the process was that the student sustained a concussion during the final data collection which delayed completion of the thesis.

Despite the challenges along the way, the practical application of the findings can already be seen, with the Balance is Better campaign being run throughout NZ (a nationwide campaign promoting youth sport participation), and the messaging to avoid specialising at young ages both in NZ Football and Sport NZ. Academic impact can be seen from the papers already published, as well as the conference presentations and the discussions that came from these.

Section 1: What Does Existing Evidence Tell Us?

Overview

The aim of Section 1 was to gain an understanding of the evidence for an association between sport specialisation and movement competency from the existing literature. This information helped to guide the methods used to assess movement competency in the following chapters.

Chapter 2 The association between sport specialisation and movement competency in youth; a systematic review

This chapter comprises the following manuscript which has been published in the *International Journal of Sport Science and Coaching* and formatted accordingly:

Zoellner, A., Whatman, C., Read, P., & Sheerin, K. (2021). The association between sport specialisation and movement competency in youth; a systematic review. *International Journal of Sport Science and Coaching, 16(4)*, 1045-1059. doi:10.1177/1747954121998456

2.0 Preface

This chapter outlines the existing literature on the association between movement competency and sport specialisation in youth athletes, in the form of a systematic review. It outlines the methods used to define and to measure movement competency and sport specialisation.

2.1 Introduction

Sport specialisation involves intensive year-round participation in a single sport to the exclusion of all others (Moesch et al., 2011). Of particular interest is the reported increase in the prevalence of 'early' specialisation, occurring before adolescence (DiCesare et al., 2019b; Jayanthi et al., 2013; Moesch et al., 2011; Myer et al., 2015). While the intentions may be to increase the chances of future athletic success, evidence suggests that realisation as an adult is not linked to achievement in youth (Kliethermes et al., 2020; Vaeyens et al., 2009). Numerous studies have also reported links between youth who specialise in a single sport and negative long-term outcomes including burnout, sport cessation and increased injury risk (Beese et al., 2015; Brenner, 2007; Jayanthi et al., 2015). The underlying mechanisms to explain the reasons for these negative consequences associated with sport specialisation remain unclear.

Research has largely focused on the long-term psycho-social effects of early specialisation in youth and the associated injury risk (Baker et al., 2009; Jayanthi & Dugas, 2017; Jayanthi et al., 2015; Wall & Côté, 2007). Young athletes who specialise in a single sport are subjected to increased exposure and intensity of competition, potentially magnifying their risk of injury (Bell et al., 2018b; DiFiori et al., 2014; Post et al., 2017a; Post et al., 2017c). Specifically, overuse injuries likely develop due to repetitive loading in distinct movement patterns and/or affordance of insufficient recovery (DiFiori et al., 2014; Myer et al., 2015). Training exclusively in one sport during childhood may also lead to the development of aberrant movement patterns and limb asymmetries (Lloyd et al., 2016; Myer et al., 2015) and compromise the development of foundational physical capacities and perceptual-cognitive skills (Lloyd et al., 2016; Myer et al., 2015). This narrow focus could lead to a reduced movement competency and a decreased ability to perform a variety of physical activities and fundamental movement skills (Bisi et al., 2017). Conversely, diverse sport participation during childhood and adolescence has been linked to enhanced movement skill development, across a greater range of foundational physical capacities and skills (Côté et al., 2009). Nonetheless, our understanding of the effects of early sport specialisation on the development of movement skill is limited.

The suggestion that early sport specialisation in youth affects movement development is plausible; however, there is no clear literature synthesis to determine the nature of this relationship. Some studies report a negative effect of early specialisation on movement competency (Myer et al., 2015), while others report no significant difference between early specialised and non-specialised youth athletes (Beese et al., 2015). Studies involving elite adult athletes indicate the potential for chronic alterations in movement patterns due to sports specialisation, especially if this occurs at a young age. For example, elite adult volleyball players have shown greater upper and lower limb strength asymmetries compared to non-elite players (Markou & Vagenas, 2006). This suggests early specialised youth volleyball players may present with greater lower limb asymmetries than those with a more diverse sporting background. In other sports, such as gymnastics, early specialised athletes may show improved balance (Asseman et al., 2008), implying that movement patterns developed in early specialised athletes are sport specific.

Therefore, the aim of this study was to systematically review the current evidence for an association between sport specialisation and movement competency in youth to give a clear synthesis, with a view towards informing future research and practice recommendations.

2.2 Methods

The inclusion criteria for this review were defined prior to commencement of the literature search in accordance with the guidelines specified by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) (Liberati et al., 2009).

2.2.1 Search strategy

Initial searches were carried out in November 2019 using the Web of Science, SPORT Discuss, Scopus, and Medline (via EBSCO) electronic databases. A secondary search was conducted in March 2020 using the same databases and identical search criteria, to find any additional studies that had been published in this time. The reference lists of included articles were also scanned. The search terms and specified combinations included: *early speciali?ation, sport speciali?ation, early sport speciali?ation, single sport, high school, youth, adolescen*; with the following keywords for movement competency: movement competenc*, movement ability, movement control, movement pattern, physical performance, coordination, fitness, motor skill, motor development, movement performance, neuromuscular control, balance, asymmetr**. An example of the search strategy is presented in Appendix D.

2.2.2 Eligibility criteria

Articles were only included where they were original, peer reviewed, and published in English. Opinion pieces, position statements, editorials, and reviews were excluded. Studies were required to report sport participation and some classification of sport specialisation when participants were aged 18 years or younger, and an assessment of movement competency was also required. Due to the lack of consistency in the definition and methods used to measure movement competency, this was left broad to include measures of movement skill or control and coordination, balance, or physical performance (for example muscular strength and endurance). Furthermore, due to the range of methods used to classify sport specialisation status, any measure of sport participation in youth that allowed quantification of specialisation was included.

2.2.3 Study selection

Potential articles of interest were selected by scanning the titles of publications from search results and the reference lists of included articles, which were then downloaded to Endnote. At this point duplicates were removed, article type and peer review status were checked, and abstracts were scanned against the eligibility criteria. The remaining articles were then read in full to ensure they met the inclusion criteria. Article selection was completed by a single author [AZ] and cross-checked by a second author [CW]. Any disagreements were discussed with all authors until a consensus was reached.

2.2.4 Data collection process

Data extraction was initially completed by a single author [AZ], then cross-checked by a second author [PR]. This included descriptive information on methodology, when and where the study took place, participants (age, level of participation, sport, gender), how sport specialisation was classified and measured, key outcome measures (including movement competency tests, variables and measures used), statistical analysis, key findings, level of specialisation of participants, and conclusions.

Due to the large range of measures and definitions used for ‘movement competency’ and ‘specialisation’, the results of different studies were described and compared based on the methods used, rather than performing meta-analysis which would be subject to large heterogeneity.

2.2.5 Study quality and risk of bias assessment

An adapted checklist based on previous research (Hindle et al., 2019) was used to analyse risk of bias and quality of included studies. This tool was chosen due to the typically non-randomised, observational nature of the existing research. Items in the checklist were evaluated on 16 points, with each scored 1 if a criterion was met or 0 if it was not met. Scores of 11-16; 6-10; and 0-5 were classified as low, satisfactory, and high risk of bias respectively. Each study was scored independently by two authors [AZ and PR], with any disagreements discussed until a consensus was reached. Explanations of the interpretations and how each point was assessed are outlined in Appendix E.

2.3 Results

2.3.1 Study selection

296 potentially relevant articles were originally identified. After duplicates were removed, 214 articles remained. Following abstract screening, 26 articles were included in a full text review. The reference lists of these articles were also scanned and revealed

one additional article. A total of 13 articles met the eligibility criteria for this review (Figure 2.1).

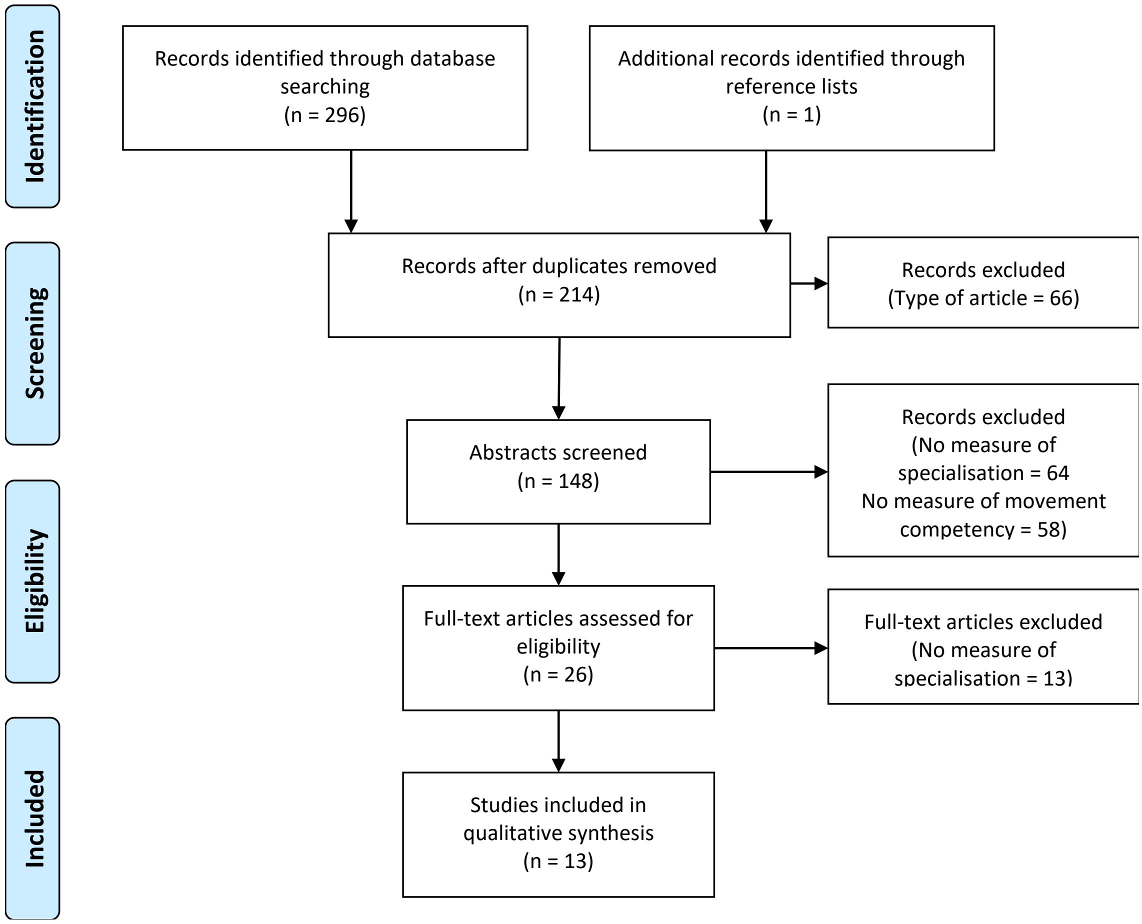

Figure 2.1: PRISMA flow diagram showing the selection process

2.3.2 Characteristics of Included Studies

The results of individual studies are reported in Table 2.1. Of the 13 included, only one followed a prospective design (DiCesare et al., 2019a), with the remaining cross-sectional and/or retrospective. The most commonly investigated sports were football (soccer) (n=7) (Beese et al., 2015; DiCesare et al., 2019a; DiCesare et al., 2019b; DiStefano et al., 2018; Herman et al., 2019; Miller et al., 2017; Peckham et al., 2018), basketball (n=7) (DiCesare et al., 2019a; DiCesare et al., 2019b; DiStefano et al., 2018; Herman et al., 2019; Miller et al., 2017; Peckham et al., 2018; Triplett et al., 2018) and volleyball (n=6) (DiCesare et al., 2019a; DiCesare et al., 2019b; Herman et al., 2019; Miller et al., 2017; Peckham et al., 2018; Triplett et al., 2018). Two studies included only one sport; football (Beese et al., 2015), and gymnastics (Root et al., 2019). Eight included multiple sports (Barfield & Oliver, 2019; DiCesare et al., 2019a; DiCesare et al., 2019b; DiStefano et al., 2018; Herman et al., 2019; Miller et al., 2017; Peckham et al., 2018; Triplett et al., 2018) and three did not report the sport (Fransen et al., 2012; Gorman et al., 2012; Sugimoto et al., 2019). The majority involved early to mid-adolescent participants (age range 12 to 16) (Barfield & Oliver, 2019; Beese et al., 2015; DiCesare et al., 2019a; DiCesare et al., 2019b; Gorman et al., 2012; Miller et al., 2017; Peckham et al., 2018; Sugimoto et al., 2019), with three studies including younger participants (as young as 6 years in one study) (DiStefano et al., 2018; Fransen et al., 2012; Root et al., 2019). Two retrospective studies included adults (aged 19-25), who were grouped based on high school sport participation (Herman et al., 2019; Triplett et al., 2018).

Table 2.1: Summary of study characteristics

Study	N; Sport (%); sex (%); Methodology	Quality analysis (RoB)	Mean age, (SD)	Specialisation definition	Specialisation (%)	Movement measure description	Summary of differences
Barfield and Oliver (2019)	49; Softball (53%), Baseball (47%); Sex NR; Descriptive, cross-sectional	11 (Low)	12.96 (2.32)	≥8 months in season and quit another sport	High (32.7%); Low (67.3%)	Single leg squat (trunk lateral flexion, trunk axial rotation, trunk flexion)	No significant difference based on level of specialisation ($p>0.05$).
Beese et al. (2015)	40; Football (100%); Female (100%); Cross-sectional	12 (Low)	HS 15.05 (1.2); Low 15.32 (1.2)	Specialised competitively in 1 sport for ≥ 1 year	High (52.5%); Low (47.5%)	Jump landing (LESS)	No significant difference based on level of specialisation ($p>0.05$).
DiCesare et al. (2019a)	158; Basketball, Football, Volleyball; Female (100%); Prospective, longitudinal	14 (Low)	13.4 (1.8)	≥2 years of participation in 1 sport and <2 years participation in any other sport	High (50%); Low (50%)	Drop jump (knee flexion ROM, knee abduction ROM, knee internal rotation ROM, knee extensor moment, knee abduction moment, knee internal rotation moment)	Significantly greater post-pubertal increase in HS for knee abduction ROM ($p=0.005$) and knee abduction moment ($p=0.006$). Significantly lower post-pubertal increase in knee extensor moment ($p=0.032$) in HS.

DiCesare et al. (2019b)	732; Basketball (47%), Football (42%), Volleyball (11%); Female (100%); Cross-sectional	15 (Low)	13.8 (2.0)	≥2 years of participation in 1 sport and <2 years participation in any other sport	High (50%); Low (50%)	Drop jump (coupling angle variability in: hip flexion-knee flexion, knee flexion-ankle flexion, hip flexion-knee abduction, knee flexion/ abduction, knee flexion/ internal rotation, knee abduction/ internal rotation)	Dominant leg coupling angle variability was significantly greater for the HS in hip flexion-knee flexion (p=0.015), knee flexion-knee abduction (p=0.014), and knee flexion-knee internal rotation (p=0.048)
DiStefano et al. (2018)	355; Football (77%), Basketball (21%); Male (34%), Female (66%); Cross-sectional	15 (Low)	11 (2)	Only played soccer or basketball in the previous year	High (25.6%); Low (74.4%)	Jump landing (LESS: scored as a continuous variable and dichotomous as good vs poor); jump (distance; football players only); t-test (time; basketball players only)	Significantly greater chance of poor performance in LESS (good/poor) (p<0.01) in HS. Significantly lower performance in broad jump (p<0.01) in HS.
Fransen et al. (2012)	735; Sport NR; Male (100%); Cross-sectional	10 (Satisfactory)	6-8 (n=161) 8-10 (n=310) 10-12 (n=264)	Participation in only 1 sport during the year in which testing took place	6-8 years - High (36.6%); Low (63.4%) 8-10 years - High (48.7%); Low (51.3%) 10-12 years - High (42.8%); Low (57.2%)	Sit up test (# reps); Push up test (# reps); Hand grip strength; Broad jump (distance); Sit-and-reach test (distance); 10x5m shuttle run (time); Endurance shuttle run (time); Motor quotient (points based on performance of walking backwards, moving sideways, hopping for height, jumping sideways)	6-8yrs: Significantly lower hand grip strength (p<0.05) in HS. 8-10yrs: no significant difference between groups. 10-12yrs: significantly lower performance in endurance shuttle run test (p<0.05), push up test (p<0.01), broad jump (p<0.01), sit-and-reach test (p<0.01) and motor quotient (p<0.01) in HS.
Gorman et al. (2012)	184; Sport NR; Male (74%), Female (26%); Cross-sectional	11 (Low)	15.9 (1.2) (SS); 15.4 (1.2) (MS)	Participate in only 1 high school sport	High (50%); Low (50%)	LYBT (absolute reach, relative reach, composite reach, reach asymmetry)	No significant difference between specialisation groups (p>0.05).

Herman et al. (2019)	Basketball (38%) 50; Volleyball (18%), Football (46%), Lacrosse (22%); Male (56%), Female (44%); Retrospective, cross-sectional	13 (Low)	No sport 23.4 (3.1); SS 23.8 (2.5); MS 24.1 (2.2)	Participated in 1 sport at varsity level in high school	SS (42%); MS (36%); No sport (22%)	Jump landing (LESS)	Significantly poorer performance in no sport (p=0.002) and SS (p=0.004) groups than MS. Significantly fewer errors (p=0.004) with each additional sport played.
Miller et al. (2017)	295; Basketball, Football, Volleyball (only female), Tennis, Male (40%) Female (60%); Cross-sectional	12 (Low)	15.6 (1.2)	Self-classified SS 3-point scale 6-point scale	SS/MS (28.4%/71.6%); 3-point High/Low (36.2%/NR); 6-point High/Low (54.9%/45.1%)	LYBT (absolute anterior reach, anterior reach asymmetry)	No significant difference in absolute anterior reach distance between specialisation groups. Anterior reach asymmetry significantly greater in mod specialised group (p=0.009).
Peckham et al. (2018)	574; Football (34%), Volleyball (17%), American Football (6%), Basketball (36%), Tennis (8%); Male (43%) Female (57%); Cross-sectional	13 (Low)	Male 16 (1); Female 15 (1), 16 (1)	3-point scale	High (31.1%) Mod (30.5%) Low (38.4%)	Jump landing (LESS)	No significant differences in LESS score between groups (p>0.05).

Root et al. (2019)	131; Gymnastics (100%); Male (36%) Female (64%); Retrospective cross-sectional	13 (Low)	10.9 (2.9)	3-point scale	High (14.5%) Mod (50.4%) Low (35.1%)	Vertical jump (height); Hanging pike test (# reps); Normalised shoulder flexibility test (ROM); Agility test (time); Pull-up test (# reps); Push-up test (# reps); Handstand test (time); Plank (time); Double leg lower (Controlled ROM); Hollow hold (time); Bridge (time); Single-leg hop (distance); UYBT (relative reach distance); LYBT (relative reach distance); Jump landing (LESS)	Significantly greater normalised shoulder flexibility in high and mod compared to low specialised (p=0.035). Significantly greater hop distance (right leg) in high specialised compared to low (p=0.039). Significantly greater Left UYBT reach distance in high and mod specialised compared to low (p=0.033). Significantly greater LYBT right (p=0.004) and left (p=0.055) in high and mod specialised compared to low.
Sugimoto et al. (2019)	236; Sport NR; Female (100%); Cross-sectional	11 (Low)	SS 15.3 (1.6); MS 14.3 (1.7)	Participate in 1 sport	High (25.4%) Low (74.6%)	ROM (knee extension, knee flexion, ankle plantarflexion); Strength (knee extensor, knee flexors, hip abductors, hip adductors); Vertical jump (height); Front plank (time)	Significantly greater right (p=0.003) and left (p=0.011) ankle plantarflexion ROM in HS. Significantly lower right knee extensor strength (p=0.05) in HS.

Triplett et al. (2018)	100; Football (21%), Volleyball (24%), Basketball (39%), Track (40%), NR sports (9%); Male (43%) Female (57%); Retrospective, cross-sectional	5 (High)	19.5 (1.7)	Number of sports participated in during high school	NR	FMS	Significant, positive correlation, FMS score improved as number of sports in high school increased. Significant, positive correlation, FMS score improved as number of sports seasons increased

Abbreviations used in table: NR=Not reported, SS=Single sport, HS=High specialised, MS=Multi-sport, Mod=Moderate, LESS=Landing error scoring system, ROM=Range of motion, LYBT=Lower body Y-Balance test, UYBT=Upper body Y-Balance test, FMS=Functional movement screen, # reps=Number of repetitions, RoB=Risk of bias

2.3.3 Methods used to classify specialisation

The most commonly applied methods were self-reported single/multi-sport (n=11) (Barfield & Oliver, 2019; Beese et al., 2015; DiCesare et al., 2019a; DiCesare et al., 2019b; DiStefano et al., 2018; Fransen et al., 2012; Gorman et al., 2012; Herman et al., 2019; Miller et al., 2017; Sugimoto et al., 2019; Triplett et al., 2018), the Jayanthi 3-point scale (n=3) (Miller et al., 2017; Peckham et al., 2018; Root et al., 2019), and Jayanthi 6-point scale (n=1) (Miller et al., 2017). The Jayanthi 3-point scale classifies athletes on a continuum of high, moderate, or low specialised, while the 6-point scale classifies athletes as specialised or not specialised (Jayanthi et al., 2015). Ratings on both scales are based on answers to a series of questions developed to cover the key aspects of the definition of specialisation, participating in a single sport, year-round, and at the exclusion of other sports. One study used all three of these methods to classify athletes; where the percentage of athletes classified as highly specialised varied based on whether this was defined as single sport (28%), using the 3-point scale (36%), or 6-point scale (55%) (Miller et al., 2017).

'Early' specialisation was discussed in seven of the included studies (Beese et al., 2015; DiCesare et al., 2019a; DiCesare et al., 2019b; Fransen et al., 2012; Miller et al., 2017; Root et al., 2019; Sugimoto et al., 2019); however, there were no consistent definitions of what age (or stage) is considered 'early'. The definition used was often vague and varied from being at a young age (Beese et al., 2015; Fransen et al., 2012; Miller et al., 2017; Root et al., 2019; Sugimoto et al., 2019), before periods of rapid growth, prior to or during puberty (DiCesare et al., 2019a; DiCesare et al., 2019b).

2.3.4 Movement competency measures

The definition and method used to measure movement competency also varied between studies. Nine included qualitative measures to classify how well a movement was performed (Barfield & Oliver, 2019; Beese et al., 2015; DiCesare et al., 2019a; DiCesare et al., 2019b; DiStefano et al., 2018; Herman et al., 2019; Peckham et al., 2018; Root et al., 2019; Triplett et al., 2018), while four used purely quantitative outcomes of performance (Fransen et al., 2012; Gorman et al., 2012; Miller et al., 2017; Sugimoto et al., 2019). Jump landing mechanics was most commonly used as primary measure for movement competency (Beese et al., 2015; DiCesare et al., 2019a; DiCesare et al., 2019b;

DiStefano et al., 2018; Herman et al., 2019; Peckham et al., 2018), including the Landing Error Scoring System (LESS) (Beese et al., 2015; DiStefano et al., 2018; Herman et al., 2019; Peckham et al., 2018), or 3D motion analysis (DiCesare et al., 2019a; DiCesare et al., 2019b). Other tests used were the lower and upper body Y-balance test (n=3) (Gorman et al., 2012; Miller et al., 2017; Root et al., 2019), broad jump distance (n=2) (DiStefano et al., 2018; Fransen et al., 2012) and vertical jump height (n=2) (Root et al., 2019; Sugimoto et al., 2019). Muscular endurance was assessed in three studies, including the number of repetitions performed in push ups (Fransen et al., 2012; Root et al., 2019), pull ups (Root et al., 2019), sit ups (Fransen et al., 2012), or the duration of abdominal hollow hold (Root et al., 2019) or front plank (Root et al., 2019; Sugimoto et al., 2019).

2.3.5 Risk of bias and quality analysis

Eleven studies were identified as having a low risk of bias (Barfield & Oliver, 2019; Beese et al., 2015; DiCesare et al., 2019a; DiCesare et al., 2019b; DiStefano et al., 2018; Fransen et al., 2012; Gorman et al., 2012; Herman et al., 2019; Miller et al., 2017; Peckham et al., 2018; Root et al., 2019; Sugimoto et al., 2019), with three scoring 15/16 (DiCesare et al., 2019a; DiCesare et al., 2019b; DiStefano et al., 2018). Detailed results are shown in Appendix F. Fransen et al. (2012) and Triplett et al. (2018) were identified as having 'satisfactory' and 'high' risk of bias respectively. The item which consistently scored poorly across studies was the confounding factors. Potential confounding factors were defined prior to assessment as stage of maturation, injury history, training and game exposure, length of specialisation, and gender.

2.3.6 Synthesis of results

Four studies found no significant difference in movement competency between specialised and non-specialised athletes (Barfield & Oliver, 2019; Beese et al., 2015; Gorman et al., 2012; Peckham et al., 2018). Of the remaining studies, seven showed some measures of movement competency were worse in high specialised athletes, but other measures did not differ (DiCesare et al., 2019a; DiCesare et al., 2019b; DiStefano et al., 2018; Fransen et al., 2012; Miller et al., 2017; Root et al., 2019; Sugimoto et al., 2019). Some differences were evident in measures of jump landing mechanics and performance, LESS, muscular strength and endurance, Y-balance, aerobic endurance, and flexibility.

Only two studies showed consistent between group differences, concluding that adult athletes who participated in two or more sports during high school showed better movement quality in the LESS (Herman et al., 2019) and functional movement screen (FMS) (Triplett et al., 2018) compared to adult athletes who specialised in a single sport during high school. Tests which consistently showed no difference based on level of specialisation included vertical jump and hop height (Fransen et al., 2012; Root et al., 2019; Sugimoto et al., 2019), time taken for tests of agility (DiStefano et al., 2018; Root et al., 2019), front plank (Root et al., 2019; Sugimoto et al., 2019), 10x5m shuttle run, walking backwards, moving sideways, or jumping sideways (Fransen et al., 2012).

2.3.6.1 Tests of jump and landing competency

Five studies investigated the association between sport specialisation and movement quality during jumping and/or landing, measured using the LESS (Beese et al., 2015; DiStefano et al., 2018; Herman et al., 2019; Peckham et al., 2018; Root et al., 2019). The results were inconsistent, with two studies reporting significantly decreased LESS performance in specialised individuals (DiStefano et al., 2018; Herman et al., 2019). The remaining three studies reported no significant difference based on specialisation (Beese et al., 2015; Peckham et al., 2018; Root et al., 2019). DiStefano et al. (2018) compared LESS outcomes as a dichotomous variable (good [<5 errors] vs bad) and a continuous outcome based on the number of errors. When analysed as a dichotomous variable, multi-sport athletes were 2.5 times more likely to display 'good' control compared to sport specialised individuals (DiStefano et al., 2018) however no differences were seen when analysing LESS score as a continuous variable. Additionally, Herman et al. (2019) reported significantly fewer errors with each additional sport played. However, most studies did not indicate significant difference in LESS when it was scored as a continuous outcome (Beese et al., 2015; DiStefano et al., 2018; Peckham et al., 2018; Root et al., 2019).

Two additional studies analysed jump landing mechanics using 3D motion analysis (DiCesare et al., 2019a; DiCesare et al., 2019b). DiCesare et al. (2019a) was the only prospective study included in this review. They reported significantly greater pre- to post-pubertal increases in highly specialised players' knee abduction range of motion and moment. Highly specialised players also showed a significantly lower pre- to post-pubertal increases in knee extensor moment. DiCesare et al. (2019b) also reported significantly greater joint coupling angle variability in highly specialised athletes for hip and knee flexion, knee flexion and abduction, and knee flexion and internal rotation. No significant differences were seen during jump landings in knee internal rotation moment (DiCesare et al., 2019a), or joint coupling angle variability of knee flexion and ankle flexion, hip flexion and knee abduction, or knee abduction and knee internal rotation (DiCesare et al., 2019b).

Broad jump distance was significantly less in highly specialised football players (DiStefano et al., 2018) and highly specialised 10–12-year-olds across a range of sports (Fransen et al., 2012). However no significant difference was seen in broad jump distance in younger athletes (Fransen et al., 2012). In a further study, including a variety of sports, hop distances were significantly lower in highly specialised compared to moderately specialised athletes on the right leg but not the left (Root et al., 2019).

2.3.6.2 Tests of balance

Reach distance during the lower body Y-balance test was evaluated in three studies (Gorman et al., 2012; Miller et al., 2017; Root et al., 2019). Two of these included reach asymmetries (Gorman et al., 2012; Miller et al., 2017) and one focused solely on anterior reach (Miller et al., 2017). Two studies identified significantly reduced reach distances (Root et al., 2019) and increased reach asymmetry (Miller et al., 2017) in highly specialised athletes, while the third reported no significant differences in these outcome measures (Gorman et al., 2012). This suggests there is very limited evidence of a relationship between Y-balance reach distance and specialisation.

2.3.6.3 Other movement tests

Muscular endurance tests showed inconsistent results with significantly poorer performance in the push up test by highly specialised athletes in one study (Fransen et al., 2012), but not another (Root et al., 2019). Fransen et al. (2012) also reported significantly poorer performance in highly specialised 10–12-year-old athletes for the endurance shuttle run test and motor quotient; however, there were no observed differences in younger age groups. Sugimoto et al. (2019) reported significantly lower knee extensor strength in the right knee for highly specialised athletes, but not in the left knee, or the knee flexors, hip adductors, or hip abductors in both legs. Range of motion at the ankle (Sugimoto et al., 2019) and shoulder (Root et al., 2019) was greater in more highly specialised athletes, but no significant differences were observed at the knee (Sugimoto et al., 2019). Barfield and Oliver (2019) measured control of the trunk during single leg squat performance and reported no significant difference between specialised and non-specialised baseball and softball players. However, significantly greater control was indicated in athletes who trained for eight months or more of the year than those who did not.

2.4 Discussion

2.4.1 Summary of evidence

This synthesis of the literature examined whether sport specialisation results in altered movement competency in youth. The results indicate that there is inconclusive evidence to support an association between movement competency and sport specialisation, with some studies showing improved movement competency in multi-sport athletes (DiCesare et al., 2019a; DiCesare et al., 2019b; DiStefano et al., 2018; Fransen et al., 2012; Herman et al., 2019; Miller et al., 2017; Root et al., 2019; Sugimoto et al., 2019; Triplett et al., 2018), while others did not (Barfield & Oliver, 2019; Beese et al., 2015; Gorman et al., 2012; Peckham et al., 2018). These inconsistencies may be due to variations in methods and definitions used, as well as limited control for confounding factors. Most studies included assessments of jump landing mechanics, with fewer assessing balance, muscular endurance, strength, and range of motion. These findings make comparisons between studies difficult, suggesting the need for consensus in definitions of both movement competency and sport specialisation.

Development of physical literacy is important to build a strong foundation of movement competency and physical activity behaviours through adolescence and into adulthood (Edwards et al., 2017; Root et al., 2018). Sport sampling (participating in more than one sport) has been suggested, which is important in youth athletes as it provides a base for sport specific skills (Šalaj et al., 2019). It also has the potential to decrease risk of injury by ensuring that athletes develop the strength and coordination to perform movements required in a safe manner (DiStefano et al., 2018) and contributes to well-being through long term physical activity involvement, giving youth the skills and confidence to participate in a range of activities (Edwards et al., 2017). While the evidence remains inconclusive, coaches, parents and sporting organisations may wish to consider adjustments to youth athletes' training and sport participation to ensure all youth are being exposed to sufficient opportunities to develop their overall movement competency, rather than just sport specific skills.

2.4.2 Jump landing mechanics

Seven studies assessed vertical drop jump landing mechanics using either the LESS (Beese et al., 2015; DiStefano et al., 2018; Herman et al., 2019; Peckham et al., 2018; Root et al., 2019) or 3D motion analysis (DiCesare et al., 2019a; DiCesare et al., 2019b). The results were inconsistent, which could in part be due to different methods used to assess landing mechanics (LESS vs 3D motion analysis), how specialisation was defined, and the range of different sports included. Analysis identified improved 3D landing mechanics in athletes participating in more than one sport (DiCesare et al., 2019a; DiCesare et al., 2019b). These findings were consistent with DiStefano et al. (2018) and Herman et al. (2019) during the LESS. Interestingly, of the studies that reported no difference in jump landing mechanics, only one controlled for maturation of participants (Root et al., 2019); however, the specialised athletes in their study were gymnasts, who would be expected to display a high level of movement control. All studies that reported a difference either controlled for maturation (DiCesare et al., 2019a; DiCesare et al., 2019b; DiStefano et al., 2018) or had participants who had reached physical maturity (Herman et al., 2019).

Of five studies classifying athletes based on the number of sports they play/played, four reported significantly poorer landing technique in athletes who participated in a single sport compared to multi-sport athletes (DiCesare et al., 2019a; DiCesare et al., 2019b; DiStefano et al., 2018; Herman et al., 2019). However, when athletes were classified using the 3-point scale, no significant difference in landing technique was shown based on specialisation status (Peckham et al., 2018; Root et al., 2019). Thus, it could be suggested that sport sampling, rather than specifically specialising in a sport is more favourable (DiStefano et al., 2018). While the exact definition of 'sport sampling' also varies across different studies, a simplified definition could be that it involves playing more than one sport, i.e., sampling a number of different sports. The distinction here being that just because an athlete is not sampling (i.e., they are playing a single sport), does not mean they are specialised (i.e., intense, year-round participation in a single sport to the exclusion of all other sport (Jayanthi et al., 2015)). This suggests that while those with limited exposure to varied movement demands exhibit poorer landing technique, this may not be caused by the intensity or volume of participation in their chosen sport. However, as mentioned earlier, there are other confounding factors (sport and maturation), making it difficult to determine whether the method of classification affected the results of these studies. Additionally, jump landing ability may be impacted by the specific sport(s) an athlete is participating in. If an athlete has regular exposure to jump landings across multiple sports, this will likely result in improved jump landing technique, which suggests chosen sport is an important factor here for both specialised and sampling athletes.

Athletes assessed participated in football (soccer) (Beese et al., 2015; DiCesare et al., 2019a; DiCesare et al., 2019b; DiStefano et al., 2018; Herman et al., 2019; Peckham et al., 2018), volleyball (DiCesare et al., 2019a; DiCesare et al., 2019b; Herman et al., 2019; Peckham et al., 2018), basketball (DiCesare et al., 2019a; DiCesare et al., 2019b; DiStefano et al., 2018; Herman et al., 2019; Peckham et al., 2018), American football (Peckham et al., 2018), tennis (Peckham et al., 2018), lacrosse (Herman et al., 2019) and gymnastics (Root et al., 2019). This diversity precludes our ability to provide definitive conclusions and may confound the results as comparing jump landing mechanics in athletes who specialise in gymnastics or volleyball with those in football or tennis presents limitations. These sports have different demands and specific movement patterns, and imbalances may occur because of increased and earlier exposure to these sports. Thus, further research is warranted to investigate specific sports. Interestingly, two studies included athletes from only one sport; football (Beese et al., 2015), and gymnastics (Root et al., 2019). Neither of these studies identified significant differences in LESS score based on level of specialisation. However, Beese et al. (2015) did report a greater proportion of multi-sport athletes (21%) scored ‘excellent’ compared to specialised athletes (10%), and a lower proportion of ‘poor’ (37%) than specialised athletes (57%). There appears to be some association between jump landing mechanics and sport specialisation, however the strength of this relationship may be weak and dependent on the sport and methods used.

The results from these studies suggest that specialising in a single sport may lead to reduced neuromuscular control during jump landings (DiCesare et al., 2019a; DiCesare et al., 2019b; DiStefano et al., 2018; Herman et al., 2019). This is based on increased ground reaction forces and knee abduction moments (DiCesare et al., 2019a), and reduced coordination of hip and knee action coupling observed in specialised athletes when compared to their non-specialised counterparts (DiCesare et al., 2019b). The observed decrements may lead to a reduced ability to effectively control ground reaction forces during landings and an increase in lower extremity injury risk (DiCesare et al., 2019b). However, with small effect sizes and absolute differences, the practical significance of these findings is questionable. While the evidence did not conclusively demonstrate reductions in neuromuscular control were present in all sport specialised athletes, the potential for increased risk of injury suggests that screening for deficits in jump landing mechanics is warranted, especially for those who specialise in a single sport. Integrative neuromuscular training may also be beneficial to improve motor skill development and decrease risk of injury (DiCesare et al., 2019a; DiCesare et al., 2019b; DiStefano et al., 2018).

2.4.3 Balance

Three studies included the lower body Y-Balance (Gorman et al., 2012; Miller et al., 2017; Root et al., 2019) and one of these also used the upper body variant of this test (Root et al., 2019). Conflicting results were shown, which may be due to the reporting of different outcome measures (absolute, relative, and composite reach distances and asymmetry). Inconsistencies were also present in sports played and the age of participants. One study included gymnasts aged 10.9 ±2.9 years (Root et al., 2019), while participants from the other studies were older (15.4 ±1.2 to 15.9 ±1.2 years) and participated in a range of different sports including basketball, football, volleyball, and tennis (Miller et al., 2017). Gymnastics requires a high level of flexibility, static and dynamic balance, so athletes who specialise in gymnastics might be expected to display better performance on the Y-Balance test as it is considered a measure of dynamic stability (Plisky et al., 2009) and ROM (Read et al., 2020). Conversely, the balance requirements in team sports such as basketball and football are different and less frequent; thus, differences in the level of specialisation and performance on balance tests in these sports may vary. Nonetheless, a potential limitation of the Y-balance test is that it measures how far a person can reach in a specified direction, with no analysis of movement quality. Thus, it may be more accurately classified as a measure of flexibility and dynamic stability (Plisky et al., 2009). From these results it appears that the relationship between Y-balance tests and sport specialisation may be sport specific and depend on the demands of each sport. Reach asymmetries of greater than 4 cm have previously been linked to increased risk of lower extremity injury (Plisky et al., 2006; Smith et al., 2015). Coaches and practitioners should be mindful of those who breach this threshold when interpreting results collected using this test with their athletes and implement targeted training programs to reduce these asymmetries.

2.4.4 Other movement components

Other components of movement competency investigated included range of motion (DiCesare et al., 2019a; DiCesare et al., 2019b; Fransen et al., 2012; Root et al., 2019; Sugimoto et al., 2019), and muscular strength and endurance (Fransen et al., 2012; Root et al., 2019; Sugimoto et al., 2019). In some cases, the tests used were chosen based on the physical capacity requirements of the sport (Root et al., 2019), whereas others selected tasks designed to identify athletes at greater risk of injury (Barfield & Oliver, 2019; DiCesare et al., 2019a; DiCesare et al., 2019b) or movements linked to gross motor skill development (Fransen et al., 2012). A broad jump was used in two studies (DiStefano et al., 2018; Fransen et al., 2012), both of which showed poorer performance in specialised athletes than multi-sport athletes. Similarly, cardiovascular fitness was lower in single sport athletes aged 10-12-year-olds than those who participated in multi-sports (Fransen et al., 2012). One could speculate that improved performances in multi-sport athletes might be due to a varied exposure to a range of physical, cognitive, and psycho-social demands (Coté et al., 2009; DiCesare et al., 2019a; DiCesare et al., 2019b; Fransen et al., 2012) but this requires further investigation. Vertical jump (Root et al., 2019; Sugimoto et al., 2019), agility (DiStefano et al., 2018; Root et al., 2019) and coordination (Fransen et al., 2012) tests showed no significant difference. Due to the range of methods and/or measures used in these studies, it is difficult to compare the results and to determine if an association is present between these additional measures of movement competency and sport specialisation.

It should be noted that across all of the reviewed studies only athletes who specialised in gymnastics were reported to have improved performance in any of the reported measures (Root et al., 2019). Gymnastics and other sports where peak performance is attained prior to physical maturity, have been suggested to require early sport specialisation in order to reach elite performance levels (Root et al., 2019). In other sports, specialising in a single sport may lead to deficits in neuromuscular control and an increased risk of injury (DiCesare et al., 2019b). Coaches and practitioners should consider including periods of unstructured free play as well as exposure to a variety of movement tasks with differing demands during training when working with youth athletes, as well as regularly screening athletes for neuromuscular control deficits (Beese et al., 2015; DiCesare et al., 2019a; DiCesare et al., 2019b; DiStefano et al., 2018).

2.4.5 Definitions of movement competency

Due to the broad range of approaches used to measure movement competency across the included studies, no standardised definition was present. It should also be noted that some measures included could be better classified as performance indicators, rather than measures of movement competency. Distance or height jumped do not give any indication of how the jump is performed. Similarly, agility tests which are measured purely as time taken to complete a set task give a better idea of speed, rather than an indication of movement quality. Using purely performance measures for these tests may not be sensitive enough to identify differences in movement mechanics or between limb differences (Hart et al., 2019; King et al., 2019). Additionally, studies have shown that although no difference is seen in performance, differences could exist in movement strategy, which could be potential indicators of increased risk of injury (Hart et al., 2019; King et al., 2019). There is a need for more comprehensive assessment of movement strategy as well as more well-defined definitions that can be applied to specific sport settings. This will enable researchers and coaches to objectively compare results and more accurately determine if there is an association between sport specialisation in different sports and movement competency development.

2.4.6 Definition of sport specialisation

The most widely accepted definition of sport specialisation is ‘intense, year-round participation in a single sport to the exclusion of all other sports’ (Moesch et al., 2011). All included studies used some or all parts of this definition; however, the method of implementation to classify athletes as specialised or not (or the level of specialisation), varied significantly between studies. Most (n=11) classified athletes dichotomously as either specialised or not, many based on the athlete self-reporting the number of sports they were currently participating in. In some cases, extra parameters were added to ensure single sport participants were specialised, including adding a lower limit (1-2 years) to the length of participation in a sport before one can be classified as being specialised (Beese et al., 2015; DiCesare et al., 2019a; DiCesare et al., 2019b). Similarly, Barfield and Oliver (2019) included a minimal time spent in training per year (8 months) as a requirement to be categorised as a specialised athlete. Three studies classified participants along a continuum, as low, moderate or highly specialised using the Jayanthi 3-point scale (Miller et al., 2017; Peckham et al., 2018; Root et al., 2019). Two studies grouped participants based on the number of sports played during high school (Herman et al., 2019; Triplett et al., 2018), indicating a more standardised approach is warranted.

This argument is further illustrated by Miller et al. (2017), who compared Y-balance results across specialisation groups using three different methods of classification; single vs multi-sport, the Jayanthi 3-point scale, and the Jayanthi 6-point scale. The Jayanthi scales were developed to cover the key aspects of specialisation; participating in a single sport, year-round, and exclusion of other sports (Jayanthi et al., 2015). The 3-point scale covers these in three questions, then classifies athletes as high, moderate, or low specialised. The 6-point scale includes an additional three questions around training volume and classifies athletes as specialised or not specialised. Miller et al. (2017) reported the percentage of participants classified as specialised or highly specialised ranged from 28% to 55% depending on the method used. Furthermore, Y-balance results showed differences in asymmetry between groups using the 3-point and 6-point scales, but not when classified as single vs multi-sport. It is also important to note that while methods used to classify athletes as specialised incorporate some aspects of the most commonly accepted definition, none include all aspects. Specifically, none of the methods used to classify athletes incorporate a measure of intensity, despite defining sport specialisation as including 'intense participation'. This suggests that intensity is an aspect which should be included in the future development of a standardised classification system to determine the level of athletes' specialisation. To date there is no consensus in the literature around the definition of early specialisation, ranging from 12 years (Côté & Hancock, 2014; Merkel, 2013) to 16 years (DiFiori et al., 2018). The terms early specialisation and sport specialisation are often used interchangeably; however, there are subtle differences. Some level of sport specialisation is required to reach elite levels of sport performance (McKay et al., 2019). However, evidence to support the importance of sport specialisation in youth athletes as a pre-requisite for future adult sporting success is lacking. A clearer consensus is required to more clearly differentiate between early specialisation and sport specialisation.

2.4.7 Quality analysis and risk of bias

Most studies were classified as having low risk of bias, with one classified as satisfactory (Fransen et al., 2012) and high risk of bias (Triplett et al., 2018) respectively. A criterion that consistently scored poorly was the control for confounding factors, which was only awarded to DiStefano et al. (2018), DiCesare et al. (2019b), and DiCesare et al. (2019a). It is expected that the risk of bias due to confounding is a domain that rates high in studies in this field of research, due to the nature and complexity of variables involved. Studies which scored a point for this item made some attempts to minimise or acknowledge the potential effects of confounders by controlling for maturation, gender, sport participation (type and/or volume) and injury history (DiCesare et al., 2019b; DiStefano et al., 2018; Root et al., 2019). Clear links have been seen in previous research between movement strategies and maturation (Read et al., 2018d). In the one prospective study included in this review, significant differences were shown in jump landing mechanics pre to post PHV (DiCesare et al., 2019b). Studies not fulfilling the criteria for control of confounding variables did not attempt to control for these (Barfield & Oliver, 2019; Beese et al., 2015; DiCesare et al., 2019a; Fransen et al., 2012; Gorman et al., 2012; Herman et al., 2019; Miller et al., 2017; Peckham et al., 2018; Sugimoto et al., 2019; Triplett et al., 2018).

Inception/time lead bias is also a methodological issue present in all the reviewed studies due to participants not being followed before the onset of specialisation. This makes it difficult to accurately determine the length of time participants have specialised. In some cases, retrospective information was sought to find out how long participants had been specialised for (DiStefano et al., 2018; Root et al., 2019; Sugimoto et al., 2019). However, this is problematic due to recall bias, and often players are simply classified based on their specialisation status at the time, with no attempt to determine how long they have been specialised. These limitations are further evident in the research of Herman et al. (2019), who reported movement competency in adulthood in relation to high school sport participation. However, athletes who went on to become successful and play for regional or higher-level teams were excluded from the study. Arguably, this group may have been the high school sport athletes whose movement competency was most affected by their sport participation. Most of the studies reviewed were also cross-sectional or retrospective in nature, with only one study collecting prospective data (DiCesare et al., 2019a). To more clearly understand if a causal relationship is present between sport specialisation and the development of movement competency, prospective longitudinal studies are needed.

2.5 Conclusions

Available evidence to demonstrate a consistent association between the level of sport specialisation and movement competency is limited. Inconsistent methods and definitions used across studies makes comparison difficult. Tasks included to measure movement competency ranged from jump landing mechanics, Y-balance tests, muscular endurance, flexibility, movement control, and cardiovascular fitness. The results were inconsistent across studies; however, the data indicate that jump landing mechanics are often significantly different in multisport athletes, whereby greater movement competency is shown. This review highlights the need for sport specific research, as well as the development and use of consistent definitions and methods to assess both level of sport specialisation and movement competency in youth athletes.

2.6 Chapter 2 Novel Contributions

In this chapter existing knowledge on the associations between sport specialisation and movement competency in youth is synthesised and critiqued. While there is some evidence supporting an association, results were inconsistent across studies, so the strength of this relationship remains unclear. Significant gaps in the current research were identified, specifically relating to the need for sport-specific research, and consistency in definitions and methods used. The need for sport-specific research is a key factor, given the associations seen are likely impacted by movements commonly performed and omitted during the sport of interest. An additional gap was the failure of most studies to account for the impact of biological maturation which is known to impact movement in youth.

Section 2: Setting the Scene, Specialisation in NZ Football

Overview

The findings of Section 1 highlighted the need for sport-specific research to help gain a clearer picture of how sport specialisation impacts youth athletes.

The studies in Section 2 investigated what was currently happening in NZ football, bringing the focus to this single sport. The aim was to determine the prevalence of specialisation in football throughout NZ, and to establish whether there was any association between level of specialisation and injury history, to give an indication of the magnitude of the 'problem'. This section also looked at a cohort of children who were 'early' specialised and investigated whether there was an association between early specialisation and movement competency.

Chapter 3 Prevalence of sport specialisation and association with injury history in football

This chapter comprises the following manuscript which has been published in *Physical Therapy in Sport* and formatted accordingly:

Zoellner, A., Whatman, C., Sheerin, K., & Read, P. (2022). Prevalence of sport specialisation and association with injury history in youth football. *Physical Therapy in Sport, 58*, 160-166. doi:10.1016/j.ptsp.2022.10.013

3.0 Preface

The previous chapter identified the need for research that is more sport-specific to determine the prevalence of sport specialisation in youth. Chapter 3 was designed to more clearly elucidate this in NZ youth football and to investigate links with injury history. Before this study, only anecdotal evidence existed to suggest a cause for concern with a high prevalence of specialisation in youth football in NZ. To examine this, a previously published survey was adapted to be football-specific, and with the assistance of NZ Football, responses from across the country were collected to give a cross-sectional overview.

3.1 Introduction

Participation in organised youth sport has increased in recent years, with a concomitant reduction in unstructured free play (Jayanthi et al., 2019; McGowan et al., 2020). In New Zealand (NZ), participation in youth football increased by 50% between 2012–2016 (New Zealand Football, 2016a). With more children involved in organised sport, a greater number are choosing to specialise in a single sport, with the goal of reaching a higher level of competition (Bell et al., 2018b; Post et al., 2019).

Sport specialisation has been defined as intense and focussed participation in a single sport for most of the year (Bell et al., 2021; Jayanthi et al., 2013). The prevalence of sport specialisation ranges from 13.4% (McGuine et al., 2017) to 41.8% (Post et al., 2020), with variation across age, sex, sport, demographics, school size and geographic location. Recent evidence suggests the prevalence of sport specialisation in NZ youth is approximately 25% (McGowan et al., 2020), but this may be higher in football (Bell et al., 2018a). Previous literature suggests specialisation prevalence may increase as competition and demand for positions increases (Bell et al., 2016). Thus, specialisation rates may be expected to increase with age, in larger schools and in sports with higher participation rates. Sport specialisation, particularly at a young age, has been linked with an increased risk of negative outcomes including overuse injuries, burnout, and dropout (Brenner, 2007; DiFiori et al., 2014; Myer et al., 2015).

Sport related injury in youth can have substantial long-term consequences including chronic problems (e.g., osteoarthritis, pain) and dropout from sport (Caine & Golightly, 2011; Post et al., 2020; Simon et al., 2019). While some studies have reported no significant association between the level of specialisation and injury risk (McKay et al., 2019), others have indicated that specialisation at a young age increases risk of injury (Bell et al., 2018a; Carder et al., 2020; Jayanthi et al., 2019; Post et al., 2020). Additionally, some studies have observed an increased risk of overuse injury, but not acute injuries (Bell et al., 2018b; Jayanthi et al., 2015). These conflicting findings may be due to the differing demands and injury risks of various sports. High volume repetitions of movements that involve large and rapid force loading characteristics (e.g., jumping) place the lower limb structures under increased strain, and thus may be associated with a greater risk of injury (Post et al., 2020). When controlling for weekly training volume, sport specialisation has been shown to increase injury risk in youth volleyball, but not basketball or football, where more varied movements are required, including running, change of direction, and jumping (Post et al., 2020). Thus, the relationship between sport specialisation and injury is likely multifactorial, including some interaction with the demands of each sport (Kliethermes et al., 2021).

Another potentially negative consequence of sport specialisation, and the increase in structured sport participation in youth, could be a decrease in the amount of unstructured free play. This may increase the risk of injury (McGowan et al., 2020) as unstructured, peer-led free play has been shown to have a protective effect against injury (Yogman et al., 2018). Current recommendations for youth sport are that weekly sport participation (hours) should not exceed their age in years (Jayanthi et al., 2019), youth should participate in no more than 8 months per year in any one sport (Bergeron et al., 2015; Lloyd et al., 2016), and the ratio of structured sport to free play hours should not exceed 2:1 (Jayanthi et al., 2015; McGowan et al., 2020).

There is a need to further investigate the prevalence of sport specialisation and associated injury risk in specific youth sports (Kliethermes et al., 2021; Pasulka et al., 2017; Post et al., 2020). The primary aim of this study was to determine the prevalence of sport specialisation in NZ youth football, and factors associated with this (sex, age, school size). The secondary aims were to examine the association between injury history and 1) sport specialisation and 2) volume of organised sport participation.

3.2 Materials and Methods

This study used a retrospective cross-sectional survey of NZ youth football players, to determine the prevalence of high, moderate, and low specialisation. Surveys were completed, on paper, at club and school games and tournaments during the 2018 and 2019 seasons. Participants were required to be aged 10–15 years, and a member of a football team playing in an organised competition. If required, participants were able to ask parents or coaches to help them complete the survey. Institutional ethical approval (#18/158) was granted prior to commencement. Due to the nature of this research, it was classified as low risk, and therefore written consent was not deemed necessary by the ethics committee.

A 15-question survey, modified from a previously used youth survey (McGowan et al., 2020), was used (Appendix G). This survey was designed to gather data on sport specialisation and participation volume. It was developed and piloted in a NZ context on similar age children and at the time was from the only study to report the reliability of answers to the specialisation questions (ICC = 0.85, high agreement). Questions were tailored to make them football specific (e.g., "have you only ever played football" instead of "have you only ever played one sport") and focused on demographics, sport specialisation, sport participation volume, and 12-month injury history. Demographic information included age, ethnicity, and school name. Participants were grouped into two age groups (under 13 and 13 years and over) based on the NZ Football youth development guidelines, where playing time, training and pitch sizes increase from age 13 (New Zealand Football, 2016b). Using information from the NZ Ministry of Education (Te Tāhuhu o te Mātauranga), along with the school's name, the school size was classified as small (<500 students), medium (500–999 students), or large (≥1000 students)(McGowan et al., 2020; McGowan, 2018; Post et al., 2017a). This was used to analyse the relationship between school size and the level of specialisation.

The main outcome measure was level of specialisation, using a football specific modification of a 3-point classification scale (Jayanthi et al., 2015). The level of specialisation was rated as high, moderate, or low, based on responses to four questions: 1) have you only ever played football; 2) have you quit other sports to focus on football; 3) over the last 12 months have you trained more than 8 months out of the year in football; and 4) do you consider football more important than other sports. Participants who answered 'yes' to three questions were ranked as highly specialised, those who answered 'yes' to two questions were moderately specialised, and those who answered 'yes' to one or no questions were classified as low specialised.

The secondary outcome measure was injury history. Injury data were limited to the previous 12-months to minimise recall bias. Any player who answered 'yes' to having been injured in the past 12 months was asked, with the help of a research assistant, to explain whether the injury was acute (i.e., sudden, due to an identifiable event) or gradual onset (i.e., no specific identifiable event). Each injury outcome ('any', 'acute' and 'gradual onset') was treated as a binary variable (either 'yes' or 'no').

Lastly, volume of organised sport and free play participation were collected (McGowan, 2018). Competition and training exposure were based on a training log completed as part of the survey. The survey contained a box with each day of the week in a separate row, for participants to fill in what they did on each day in the average week in summer and winter. Summer sports were identified by 'S", winter sports with 'W', and all year sports with 'AY'. Weekly organised sport participation was calculated for summer (school terms 1 and 4; October – March), winter (school terms 2 and 3; April – September), and the whole year. Average weekly exposure was calculated by finding the average of summer and winter hours and then adding the 'whole year' hours. Weekly participation volume was classified as exceeding current recommendations if the hours per week were greater than the participant's age in years. Annual organised sport participation was classified as meeting or exceeding current recommendations based on the response to the question "over the last 12 months have you trained more than 8 months out of the year in football?". Volume of free play was assessed based on a question asking about weekly hours of non-structured exercise/activity. Participants were given examples of free play activities such as surfing, playing in the park, and taking the dog for a walk. Their responses were discussed with the research assistant if they were unsure. Ratio of structured sport to free play was calculated by dividing the number of hours spent in structured sport each week (average weekly exposure) by the number of hours spent in free play each week.

3.2.1 Data analysis

Survey data were manually transferred to an Excel spreadsheet. Questionnaires with incomplete answers to specialisation or demographic questions were removed from the analysis completely. Those with incomplete responses to injury or sport participation questions were removed from the analysis of injury data. Analysis was conducted using the Statistical Programme for Social Sciences v26 (IBM SPSS, Chicago). Categorical data are presented as frequencies and percentages. Continuous data are presented as means and standard deviations (SD) for normally distributed data, or median and interquartile range (IQR) if not normally distributed. A statistical significance level of $p \leq 0.05$ was set a priori.

The associations between level of specialisation (low, moderate, high) and sex (male, female), age (under 13 years, 13 years and over), and school size (small, medium, large) were analysed using chi square tests for independence. Cramer's V value (which takes into account degrees of freedom [df]) was used to determine the effect size (ES). For 1 df, ES were small≥0.01, medium≥0.30, large≥0.50. ES for 2df were small≥0.07, medium≥0.21, large≥0.35. Differences in organised sport participation and free play (hours/week) among the three levels of specialisation were analysed using a Kruskal-Wallis test, as the sport participation and free play variables were not normally distributed. Post-hoc Mann-Whitney U tests with Bonferroni corrections were used for pairwise comparisons.

Binary logistic regression with block entry was used to determine the association between injury history (injury reported vs. no injury reported) with level of specialisation (high, moderate, low) and volume of organised sport participation. Injury outcomes were separated into three binary (yes/no) categories: 'any injury', 'gradual onset injury' and 'acute injury'. Volume of sport participation was analysed based on four explanatory variables: total hours per week, training more hours per week than age in years (yes/no), training for more than 8 months of the year (yes/no), and exceeding a 2:1 ratio of organised sport to free play (yes/no). Results are presented as unadjusted odds ratios

(OR) with 95% confidence intervals (CI). Finally, adjusted OR and 95%CI were calculated to control for potential confounders known to be associated with injury risk (sex, age, and either volume of sport participation or level of sport specialisation, as appropriate) (Jayanthi et al., 2015; McGowan et al., 2020; Post et al., 2017c).

3.3 Results

3.3.1 Participant characteristics

414 participants (12.8 ±1.1 years; 211 boys) completed the survey. Surveys with incomplete demographic or specialisation data (n=15) were excluded from the analysis of the prevalence of specialisation, leaving 399 (96% of total sample). A further 59 participants were excluded from the analysis of injury associations due to incomplete injury data, resulting in 340 (82% of total sample) being included in the injury analysis.

3.3.2 Prevalence of specialisation

43% (n=172) of participants were classified as highly specialised in football, 38% (n=152) as moderately specialised and 19% (n=75) as low specialised. Significant associations between level of specialisation and age, sex, and school size were found (Table 3.1).

Table 3.1: Association of sex, age, and school size with level of specialisation

		Specialisation level			Cramer's V	p-value
		Low (%)	Moderate (%)	High (%)		
Sex	Male	36 (15%)*	92 (37%)	120 (48%)*	0.20#	<0.01
	Female	41 (27%)*	59 (39%)	51 (34%)*		
Age	10-12.99	33 (19%)	81 (47%)*	60 (34%)*	0.20#	<0.01
	13+	44 (20%)	70 (31%)*	111 (49%)*		
School size	Small	13 (23%)*	23 (40%)	21 (37%)*	0.21#	<0.01
	Medium	36 (26%)*	53 (38%)	50 (36%)*		
	Large	16 (11%)*	49 (35%)	76 (54%)*		

*=p≤0.05. #medium effect size

A higher proportion of boys were classified as highly specialised compared to girls (medium ES; p<0.01). More participants aged 13 and over were classified as highly specialised, compared to those under 13 (medium ES; p<0.01). Large and medium size schools were overrepresented (n=327; 82% of all participants), a greater proportion of participants in large schools were highly specialised (54%) and a smaller proportion were low specialised (11%), compared to medium (36% high, 26% low) and small sized schools (37% high, 23% low) (medium ES; p<0.01).

3.3.3 Volume of sport participation

Weekly volume of organised sport participation was significantly higher (X2[2]=7.1, p=0.03) in moderately specialised participants (median=8.0hr, IQR=6.0–10.4hr), compared to both low (median=7.0hr, IQR=4.0–9.0hr) and high specialised (median=7.0hr, IQR=6.0–9.5hr) (Table 3.2). No significant differences (X2[2]=5.2, p=0.07) were seen in weekly volume of free play between low (median=5.3hr, IQR=2.0–10.0hr), moderate (median=4.0hr, IQR=1.0–7.0hr) and high (median=4.0hr, IQR=0.8–7.0hr) specialised participants.

Table 3.2: Volume of sport participation

	Specialisation level			p-value
	Low	Moderate	High	
Weekly organised sport participation (hr) median (IQR)	7.0 (4.0–9.0)	8.0 (6.0–10.4)	7.0 (6.0–9.5)	0.03*
Weekly free play (hr) median (IQR)	5.3 (2.0–10.0)	4.0 (1.0–7.0)	4.0 (0.8–7.0)	0.07
Exceeding 2:1 sport to free play ratio (n; %)	10 (20)	35 (38)	37 (35)	0.07

*=p≤0.05

3.3.4 Injury history

One or more injuries were reported by 287 (84%) of participants in the previous 12 months. Of these, 52% (n=149) reported that one or more of their injuries was 'gradual onset' and 77% (n=221) reported that one or more of their injuries was 'acute'. After controlling for confounding variables (age, sex, and weekly sport participation volume), highly specialised participants had 4.2 times higher odds of reporting a gradual onset injury (95%CI=1.48–11.74, P=0.01) compared to low specialised participants (Table 3.3). No significant associations existed in the adjusted or unadjusted models between level of specialisation and 'any injury', or 'acute injury' (Table 3.3).

Table 3.3: Association between level of specialisation and injury

Injury type	Specialisation category	Unadjusted OR[a] (95% CI)	p-value	Adjusted OR[b] (95% CI)	p-value
Any	Low	-	-	-	-
	Moderate	0.71 (0.31–1.65)	0.43	0.67 (0.28–1.59)	0.37
	High	1.15 (0.49–2.72)	0.75	1.17 (0.48–2.85)	0.74
Gradual onset	Low	-	-	-	-
	Moderate	1.95 (0.77–4.95)	0.16	2.68 (0.97–7.44)	0.06
	High	2.34 (0.98–5.55)	0.05	4.17 (1.48–11.74)*	<0.01
Acute	Low	-	-	-	-
	Moderate	0.65 (0.20–2.08)	0.47	0.53 (0.16–1.80)	0.31
	High	0.32 (0.20–1.70)	0.32	0.35 (0.10–1.20)	0.10

OR=odds ratio. CI=confidence interval. *=p≤0.05.

a = Univariate logistic regression analysis, reference group was low specialisation.

b = Multivariate logistic regression analysis. Models controlled for independently associated confounding variables: weekly organised sport participation volume, age, and sex.

'Any injury' or 'acute injury' were not significantly associated with sport participation volume (weekly or training more than 8 months of the year) (Table 3.4). Associations between 'gradual onset injury' and sport participation volume (both weekly volume and training more than 8 months of the year) were significant in both unadjusted and adjusted models. Those training in football for more than 8 months of the year had 2.9 times greater odds of reporting a 'gradual onset injury' (95%CI=1.17–6.99, p=0.02) compared to those who trained for less than 8 months of the year. Increased hours of organised sport per week also increased the odds of reporting a 'gradual onset injury' (OR=1.12, 95%CI=1.00–1.24. p=0.05).

78 participants (23%) reported exceeding a 2:1 ratio of organised sport participation to free play, and a small proportion of participants (9%, n=31) exceeded current weekly sport participation volume recommendation (more hours per week than age in years). No significant associations were seen between injury ('any', 'acute', or 'gradual onset') and exceeding the sport participation volume recommendations (Table 3.4).

Table 3.4: Association between organised sport participation volume and injury history

Volume measure	Injury type	Unadjusted OR[a] (95% CI)	p-value	Adjusted OR[b] (95% CI)	p-value
Playing football >8 months of the year[c] (n=315)	Any	1.40 (0.67–2.94)	0.37	1.25 (0.59–2.69)	0.56
	Gradual onset	2.61 (1.13–6.01)*	0.03	2.86 (1.17–6.99)*	0.02
	Acute	0.47 (0.15–1.44)	0.18	0.37 (0.12–1.17)	0.09
Weekly organised sport participation volume (hours)[d]	Any	1.11 (1.00–1.23)	0.06	1.10 (1.00–1.23)	0.06
	Gradual onset	1.11 (1.01–1.23)*	0.04	1.12 (1.00–1.24)*	0.05
	Acute	1.03 (0.92–1.16)	0.63	1.01 (0.90–1.14)	0.84
Exceeding 2:1 ratio organised sport:free play[e] (n=78)*	Any	1.62 (0.73–3.60)	0.24	1.23 (0.50–3.01)	0.66
	Gradual onset	1.16 (0.54–2.48)	0.70	0.64 (0.25–1.67)	0.64
	Acute	0.90 (0.38–2.16)	0.81	0.78 (0.29–2.13)	0.63
Exceeding weekly volume recommendation[d] (n=31)	Any	1.63 (0.48–5.58)	0.43	1.87 (0.53–6.53)	0.33
	Gradual onset	1.34 (0.49–3.70)	0.57	1.56 (0.53–4.54)	0.42
	Acute	1.50 (0.41–5.51)	0.54	1.40 (0.37–5.34)	0.63

OR=odds ratio. CI=confidence interval. *=p≤0.05. n=number of participants exceeding recommendation.

a = Univariate logistic regression analysis. b = Multivariate logistic regression analysis. Models controlled for independently associated confounding variables. c = sex, age, and weekly organised sport participation volume. d = sex, age, and level of specialisation. e = sex, age, weekly organised sport participation volume, and level of specialisation.

3.4 Discussion

The primary aim of this study was to determine the prevalence of sport specialisation in NZ youth football. The frequency of high specialisation (43%) was higher than previously reported in the available literature, both in football (Bell et al., 2018a; Post et al., 2020) and in a NZ youth population (McGowan et al., 2020). Boys were more likely to be highly specialised than girls. Previous research has indicated that in general girls are more likely to specialise than boys (Post et al., 2017c), however this trend has not been observed in football (Bell et al., 2018a). This likely reflects that while female participation numbers are increasing in football in NZ (New Zealand Football, 2016a) and the first professional women's football team was launched in NZ in 2021, overall participation is still male dominant and professional pathways for women are less visible. There is likely more competition for positions in male teams, potentially resulting in players specialising to focus on football in the hopes of increasing chances for selection and future success (Jayanthi et al., 2019).

The results of this study showed that older participants were more likely to be highly specialised. This finding is similar to those of others who have reported specialisation levels increase with age (Post et al., 2017b). NZ Football encourages junior players (under 13 years) to focus on developing general movement before progressing to the youth (age 13+) framework, which places a greater emphasis on developing football specific skills (New Zealand Football, 2016b). However, with peak growth in boys typically occurring between the ages of 13 and 15 (Malina et al., 2015), recommendations have been made to delay specialisation until after this age, even as late as age 16 (Bergeron et al., 2015; Lloyd et al., 2016). Given peak growth generally occurs earlier in girls (Cole et al., 2014), it is likely sex specific recommendations are needed for the appropriate age to specialise. However, in developing these recommendations, it is also important to consider energy availability (in boys and girls, especially in aesthetic or weight category sports) and menarche (in girls). More research is needed to determine this. Our data indicate that almost half of the participants in the current study are specialising in football prior to the recommended chronological age.

Available evidence suggests football players who achieve elite status in adulthood tend to specialise at an older age than non-elites (Haugaasen et al., 2014; Hornig et al., 2016). For a minority of sports (e.g., gymnastics, diving, or figure skating), there may be biomechanical advantages to specialising prior to reaching full physical maturity (Kliethermes et al., 2021). However, for most sports, peak performance occurs after physical maturation is complete (Côté & Hancock, 2014; DiFiori et al., 2014). The evidence indicates early sport specialisation is not needed to reach elite levels, and youth athletes benefit from diverse sport participation during their youth through decreased risk of gradual onset injury, increased exposure to varied movement challenges, and decreased risk of burnout and dropout (Bridge & Toms, 2013; Kliethermes et al., 2020). However, while recommendations are to delay specialisation until after puberty or age 16 (Côté et al., 2009; DiFiori et al., 2018), this may not be realistic in all countries or sports. Sporting organisations and coaches should be aware that in some cases youth athletes are specialising prior to physical maturation. In these cases, athletes should be carefully monitored, and training adjusted accordingly, to maximise exposure to and development of a broad range of motor skills to reduce the risk of overtraining and gradual onset injury.

Participants from small and medium sized schools were more likely to be low specialised, and less likely to be highly specialised, than those from large schools. Smaller schools may have less competition for positions in teams meaning less of a drive to focus and specialise in a single sport. There may also be a bias towards larger schools as part of talent identification and recruitment programmes. These participants may have greater access to higher quality coaching staff and training facilities, with more opportunity for specialisation and exposure to academy frameworks (Fraser-Thomas et al., 2005). On the other hand, smaller schools may need players to be involved in multiple sports to enable them to field competitive teams (Bell et al., 2016). Parents and coaches should keep this in mind when planning a child's sport participation, ensuring that regardless of the school size, youth are being exposed to and developing a range of movement competencies and being allowed sufficient rest and recovery.

A secondary aim of this study was to investigate the association between sport specialisation and injury history. No significant associations existed between level of specialisation and 'any injury' or 'acute injury' in accordance with previous research (McGowan et al., 2020). Some previous studies involving NZ youth participating in a variety of sports (McGowan et al., 2020), and highly specialised basketball or football players in the USA (Post et al., 2020) also reported no association between level of specialisation and overuse injury. However, we observed that highly specialised football players were 4.2 times more likely to report a 'gradual onset injury' in the previous 12 months than low specialised players, even when controlling for weekly sport participation volume. These differences could be because of the sport specific associations of specialisation and injury risk which may not have been evident when analysing multiple sports and differences in football player development programmes across countries. This is further supported by the increased incidence of knee injuries reported in specialised soccer players by Bell et al. (2018a), however they observed an increase in both overuse and acute injuries.

When focusing on an athlete's main sport, previous evidence suggests highly specialised athletes (age 16.1 ±1.1) were more likely to report overuse injuries than lower specialised athletes; however, weekly participation volume was not controlled for (Bell et al., 2018a; McGuine et al., 2017). We observed an association between specialisation and 'gradual onset injury', but not 'acute injury', even when controlling for weekly participation volume. This suggests that while a greater volume of training is associated with increased odds of reporting a gradual onset injury, there is also an independent risk due to specialising in a single sport (Jayanthi et al., 2015), but this may not be the case for acute injuries. A contributing factor may be high volumes of homogenous training and competition involving repetitive loads and the absence of exposure to more varied exercise prescription that would likely encourage greater neuromuscular development (Jayanthi et al., 2015). Cumulatively, our results suggest specialisation is not a risk factor for acute injury, but it may increase the risk of sustaining an overuse injury, even when controlling for weekly participation volume (Bell et al., 2016; Jayanthi et al., 2015). Overall, rates of injury in this cohort were high, with 84% reporting at least one injury in the past 12 months. Similar high rates were reported in a previous study in NZ (McGowan et al., 2020) and indicate the need for a focus on development of injury prevention strategies in youth sport in NZ.

The final aim of this study was to investigate associations between injury history and exceeding organised sport participation volume recommendations. Most of the participants in this study (93%) participated in football for more than 8 months of the year. Even when controlling for weekly training volume, these participants were 2.9 times more likely to report a 'gradual onset injury' than those who trained 8 months or less. This supports previous recommendations that youth athletes should not train for more than 8 months of the year in one sport (Jayanthi et al., 2015; McGowan et al., 2020; Post et al., 2017c). Rest and recovery periods should be included in youth athletes' schedules to reduce the risk of overuse injury (DiFiori et al., 2014) and ensure adequate physical and psychological recovery. Taking 3–4 months rest from specific sports each year allows youths' bodies time to recover from chronic loading, especially in sports where the specific movement patterns to which the athletes are repetitively exposed fall within a narrow range (Lloyd et al., 2016) and to adjust to factors related to normal growth and development (Olsen et al., 2006; Post et al., 2017c). It should be noted that this recommendation is not for athletes to be inactive for 3–4 months, but that they take time away from their primary sport. They should be encouraged to explore other sports and forms of activity including free play.

It has also been recommended that children do not exceed a 2:1 ratio of organised sport to free play to reduce the risk of overuse injury (Jayanthi et al., 2015; McGowan et al., 2020). Peer-led free play has previously been reported to have a protective effect as the duration and intensity of participation is moderated by the child (Jayanthi et al., 2015), and free play may lead to greater exposure to more diverse motor skills. No association between exceeding a 2:1 ratio of organised sport to free play and any type of injury was observed in this study. While there is less structure in free play than organised sport, a good coach may provide greater variety of activities to promote greater motor skill development (Côté et al., 2009). In addition, a relatively small proportion of participants (23%) exceeded this ratio.

Only a small proportion (9%) of participants completed more organised sport participation hours per week than their age in years. Exceeding this threshold was not associated with a history of injury, although we acknowledge the small sample size. However, a higher weekly participation volume was associated with increased odds of reporting a 'gradual onset injury' (approximately 10% increase for every extra hour per week). Similar results have been found in other studies, where youth participated in less hours per week than their age, but still reported more overuse injuries (McGowan et al., 2020; Purnell et al., 2010; Rose et al., 2008). Therefore, it is suggested that volume recommendations may be too high, particularly during periods of rapid growth (McGowan et al., 2020).

High rates of both injury and specialisation were found in this NZ youth football cohort. These rates suggest all youth football players in this cohort could benefit from participating in an injury prevention programme and/or targeted screening and strength and conditioning. Additionally, there may be a need for improved tracking or oversight of overall sporting commitments of these youth players to ensure players are not overtraining, have sufficient recovery between sessions, and training is adjusted as needed to accommodate other commitments and maturational changes. Alongside this, there may be a need for improved coach education on how best to support the development of these young players.

We acknowledge that there are limitations to this study. We asked participants to recall their football (and other sporting) participation, as well as their injury history over the previous 12 months. This may limit their ability to accurately recall the required information corresponding to this period. To minimise this limitation, cues were included in some of the questions to help participants remember, for example in the training and participation log, examples were included for summer and winter sports and research assistants were available to help with this, asking what participants did in each school term. Additionally, this survey (including the training and sport participation section) was piloted in a similar age NZ youth cohort and developed to maximise understanding and ease of completion (McGowan, 2018). Despite these factors, we acknowledge that there are likely limitations in the validity and reliability of these data and the results should be interpreted accordingly. We also acknowledge that there is a potential confounding effect due to previous injury (Emery et al., 2005), and there is limited information on the nature of the injury (mechanism, time-loss, location). While an attempt was made to collect this information, the quality of responses to these questions was poor, thus the decision was made to exclude these. Future research should attempt to better quantify these factors and/or prospectively follow players rather than relying on recall. Additional research is also warranted to gain a better understanding of the mechanisms of gradual onset injuries in youth football. Additionally, future research should investigate the suitability of current volume recommendations in youth football, in particular the weekly volume recommendation relative to age and maturation.

3.5 Conclusion

High prevalence of specialisation was seen in NZ youth football players in the current study and is more common in boys, larger schools and with increasing age. Highly specialised participants were four times more likely to report a history of gradual onset injury. Reporting a history of gradual onset injury was also associated with playing football for more than 8 months of the year and increased weekly organised sport participation volume, regardless of level of specialisation.

3.6 Chapter 3 Novel Contributions

The findings of this chapter more clearly elucidate the prevalence of specialisation in NZ youth football players using an objective approach. Limited studies have investigated youth sport specialisation in NZ, and this is the first specific to football. This study confirms anecdotal reports that there is a high proportion of youth football players in NZ specialising, and that there are high rates of injuries. Globally, a need has been identified for evidence defining the relationship between youth sport specialisation, and injury risk, controlling for the injury type (acute/overuse), and volume of participation. The data presented provide novel insights to indicate there is a relationship between specialisation and gradual onset injury independent of participation volume. Potential mechanisms of these injuries warrant further exploration.

Chapter 4 Does early specialisation improve movement competency in junior football players?

This chapter comprises the following manuscript which has been submitted to *Pediatric Exercise Science* and formatted accordingly:

Zoellner, A., Whatman, C., Sheerin, K., & Read, P. (2022). Does early specialisation improve movement competency in junior football players? *Pediatric Exercise Science,* under review.

4.0 Preface

This chapter provides sport-specific research to examine the association between (early) sport specialisation and movement competency. This is the only chapter that looks specifically at 'early' specialisation, as all participants are younger than 12 years, which is the lowest cut-off reported for 'early' specialisation. All other chapters look at 'sport specialisation', but not specifically 'early'. Changes in movement competency have been suggested as a contributing factor to explain the association between sport specialisation and gradual onset injuries independent of volume. The Y-balance test and the landing error scoring system were used to assess movement competency. These tests were identified from the findings in Chapter 2 and have been commonly used in youth athletes, with some research reporting differences based on level of specialisation in other cohorts.

4.1 Introduction

Sport specialisation has been defined as focused, intentional training, year-round, in a single sport (Bell et al., 2021). High rates of specialisation are consistently reported in young athletes across a number of sports (Bell et al., 2016; Post et al., 2017b; Post et al., 2017c; Zoellner et al., 2022). Proposed reasons for this include a desire to increase chances of future selection, scholarships and opportunities to play professionally (Normand et al., 2017; Post et al., 2019). However, a number of studies indicate that in most sports, athletes do not need to specialise at a young age in order to achieve elite-level performance later in life (Kliethermes et al., 2020; Murata et al., 2022). More so, delayed specialisation has been reported as more commonly in adult elite-level performers compared to their sub-elite counterparts (Hornig et al., 2016; Kliethermes et al., 2020).

While some level of specialisation is needed to reach elite and/or professional levels, 'early' sport specialisation has been associated with negative long-term outcomes for youth athletes, including burnout, dropout, and increased risk of injury (Beese et al., 2015; Brenner, 2007; Jayanthi et al., 2015; Wall & Côté, 2007). Various international consensus statements have been published discouraging early specialisation (Bergeron et al., 2015; DiFiori et al., 2014; LaPrade et al., 2016), but no agreement has been reached on the appropriate age for specialisation, and indeed what constitutes 'early'. Current evidence suggests that specialisation should be delayed until after physical maturation or late adolescence (Jayanthi et al., 2019; LaPrade et al., 2016).

Later specialisation promotes exposure to more varied movement and coordination tasks in young athletes and this may optimise skill learning (Côté et al., 2009). Additionally, pre-puberty has been identified as an important time to learn fundamental, broad motor skills to maximise the future potential due to increased neural plasticity (Myer et al., 2011). Thus, delaying specialisation is advised to allow more time for young athletes to develop enhanced competency in a broad range of movement skills (Jayanthi et al., 2019; Myer et al., 2015). In adolescence, young athletes also undergo rapid growth with alterations in neuromuscular control (Beese et al., 2015; DiCesare et al., 2019a; DiStefano et al., 2018; Miller et al., 2017). These developmental periods heighten injury risk (van der Sluis et al., 2014), especially if combined with the subsequent increases in training load and intensity often associated with early specialisation (Brenner & Council On Sports Medicine and Fitness, 2016).

Exposure to varied movements and the ability to respond to different situational demands is vital in preparing young athletes for future sports performance (Côté et al., 2009). Recent research has indicated that following injury and return to sport, football athletes develop movement strategies to allow them to achieve the same outcomes as non-injured players, despite their physical limitations on the involved limb (Hart et al., 2019). Movement strategies will emerge under constraints from different tasks and environments, thus exposure to greater variability may allow athletes to develop a wider range of movement solutions (Côté & Hancock, 2014). Specifically, football players favour kicking with their dominant leg, which results in increased stability in the supporting leg (Atkins et al., 2016). Jump-landing performance may also be enhanced on the non-dominant kicking leg (Read et al., 2018b; Read et al., 2018d), leading to imbalances in force transfer, muscle activation and motor control (Atkins et al., 2016; Read et al., 2016a). However, more studies are needed to elucidate the relationship between early specialisation and movement competency, and to examine if movement strategies emerge that may predispose these young athletes to a heightened risk of injury.

Given the high proportion of youth players specialising 'early' in football, and the potential for this to impact on movement skill development, the aim of this study was to investigate if differences exist in the movement competency of pre-pubertal football players based on their level of specialisation.

4.2 Methods

This cross-sectional study included movement tests and a survey of current and past sport participation. Institutional ethical approval was granted prior to recruitment and data collection. All participants provided informed written assent, and their parents or caregivers gave informed consent. The movement tests included the Y-balance anterior reach distance (absolute and relative to leg length) and drop jumps (DJ) assessed using the Landing Error Scoring System (LESS). Testing took place in the evenings, during normal training times, with participants performing their normal training warmup prior to testing. At each session, the tests were explained to the participants, and they were given time to familiarise themselves to ensure they completed the task as instructed. Familiarisation involved participants practising each test at least four times to minimise variation due to any learning effect (Munro & Herrington, 2011).

4.2.1 Participants

Thirty-five boys aged 10.2 ±1.1 years (height: 140.7 ±8.7 cm; body mass: 36.6 ±8.6 kg) volunteered to take part. Participants were recruited from football academies in Auckland, New Zealand (NZ) during the competitive season. Academy trainings occurred on two nights per week for this age group, in addition to their club team training (once per week) and match. Participants were required to be at least 1-year pre-peak height velocity (PHV), and currently free from injury, to minimise maturational and/or injury effects on movement. Additionally, all participants were younger than 12 years of age, the most commonly reported chronological age-based threshold for defining early specialisation (Mosher et al., 2020). Other sports participants were involved in included

Tae kwon do, cross country running, cricket, skateboarding, basketball, swimming, karate, rugby, rugby league, netball, and futsal.

4.2.2 Procedures

4.2.2.1 Maturity assessment

Maturation offsets were calculated using a validated somatic equation (Mirwald et al., 2002). All estimates were based on measures of standing and sitting heights, body mass, and leg length (measured whilst standing in anatomical position, from the anterior superior iliac spine to the medial malleolus) (Miller et al., 2017).

4.2.2.2 Level of specialisation

Sport history questionnaires (Appendix H) were used to determine the current level of specialisation, and which sports boys participated in, at each age since they began football. Questionnaires were completed with the help of a parent and used to determine how long participants had been specialised (Moesch et al., 2011). The level of specialisation was determined based on their answers to four questions: 1) Is football more important than any other sport? 2) Do you train more than 8 months of the year in football? 3) Have you quit other sports to focus on football? And 4) Have you only ever played football?' Players who answered 'yes' to three questions were classified as highly specialised (note the maximum score was three as a 'yes' answer to either of the last two would imply 'no' to the other). Those who answered 'yes' to two questions were classified as moderately specialised, and 'yes' to one or less were classified as low specialised. Classification of players was determined after data collection to ensure researchers were blinded to the level of specialisation during testing.

4.2.2.3 Movement competency

Y-Balance tests were performed on a custom-made Y-balance test kit consisting of a small wooden box with three poles attached in a 'y' shape (Figure 4.1). A block was placed on each pole that could easily slide along the pole to indicate reach distance. Participants adopted a single-leg stance on the box in the middle with their toes behind a line, and their hands on their hips. They were then instructed to push the block along the pole as far as possible while maintaining balance, without putting weight on the block or placing their foot on the ground. When participants had pushed the block as far as possible, they returned their foot to the centre without touching down. If any of these instructions were not adhered to, participants were asked to repeat that trial. The reach distance was recorded from the box to the back of the block. The anterior reach only was tested for logistical reasons, and due to its stronger associations with injury risk compared to the posterior medial and lateral directions (Plisky et al., 2006). Limb order was randomised, with three trials on each leg. Absolute anterior reach distances were compared, as well as reach distance relative to leg length (%LL). Reach asymmetry was also calculated, as the percentage difference between legs (absolute difference between legs/greatest reach distance*100).

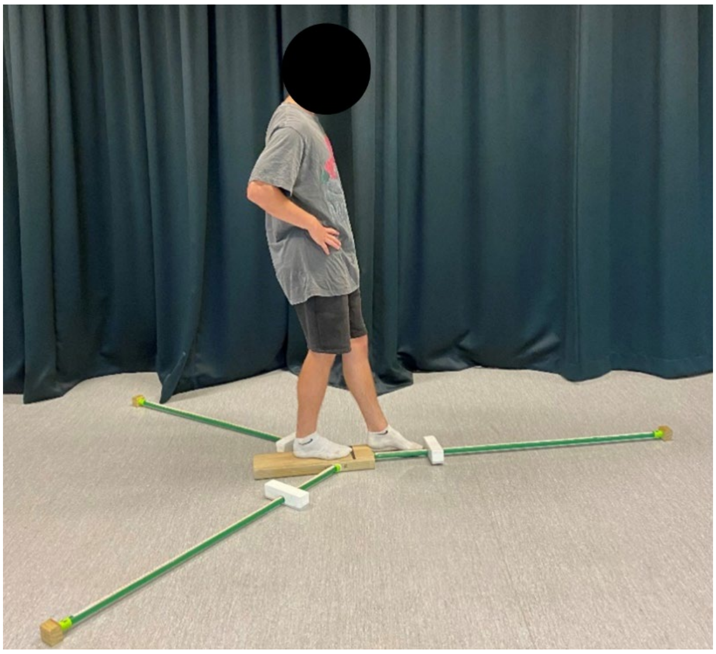
Figure 4.1: Y-Balance anterior reach

Drop jumps were performed from a 30cm box with a cross on the floor at a distance half the participant's standing height (Figure 4.2). Instructions were to drop down, land on the cross with both feet, and perform a vertical jump for maximum height while minimising ground contact time. Frontal and sagittal plane video (Sony HDR-CX130 Handycam, Sony Corporation of America, New York, NY) was recorded (3m from the front and side of the cross on the floor at a height of 1m). Cameras were set to record in portrait orientation. Three trials were completed by each participant.

Figure 4.2: Drop jump flight phase

Jump-landings were rated using the 17-item scoring system developed by Padua et al. (2015) (Table 4.1). Individuals were given a score that equated to a count of errors displayed during the trial. A lower score indicated fewer errors and thus better technique. Videos were rated independently by two individuals who were experienced in movement analysis and blinded to the specialisation classification of participants. Videos were viewed in freely available analysis software (Kinovea v0.9.3), paused at the time point of interest (e.g., initial contact) and replayed as many times as necessary to be confident of the score. One score was given based on the three trials. An error was counted if it was displayed in two or more of the trials. Scores were compared between raters and any differences were discussed. Videos were then reviewed until a consensus was reached.

Jump-landing competency was classified based on previous research (Beese et al., 2015; Padua et al., 2009), as ‘excellent’ (0-3 errors), ‘good’ (4-5 errors), ‘moderate’ (6 errors), or ‘poor’ (≥7 errors). DJ data for some participants were excluded, participant numbers included in each group for each analysis are reported in the relevant tables.

Table 4.1: Landing Error Scoring System criteria

Time point	Criterion	Rating
Initial contact	Knee flexion more than 30°	0 = Yes 1 = No
	Hips are flexed	0 = Yes 1 = No
	Trunk is in front of hips	0 = Yes 1 = No
	Ankle plantar flexion: lands toe to heel	0 = Yes 1 = No
	Knee valgus: patella is not medial to midfoot	0 = Yes 1 = No
	No lateral trunk flexion	0 = Yes 1 = No
	Stance width	0 = Feet shoulder width apart 1 = Feet wider than shoulder width or narrower than shoulder width
	Feet land symmetrically	0 = Yes 1 = No
Between initial contact and maximum knee flexion	Foot rotation	0 = Feet not internally or externally rotated more than 30° 1 = Feet internally or externally rotated more than 30°
	Knees flex 45° or more	0 = Yes 1 = No
	Hip flexion increases	0 = Yes 1 = No
	Trunk flexion increases	0 = Yes 1 = No
Point of maximum medial knee displacement	Midpoint of patella does not move medial to midfoot	0 = Yes 1 = No
Overall	Amount of trunk, hip, and knee joint displacement throughout	0 = Large (soft landing) 1 = Some (average landing) 2 = Very little (stiff landing)
	Overall impression of softness of landing and frontal- and transverse-plane movement	0 = Excellent (soft, no frontal or transverse plane motion) 1 = Average 2 = Poor (stiff and/or large frontal- or transverse-plane motion)

4.2.3 Statistical analyses

Mean and 95% confidence intervals (95%CI) are reported for continuous data. A significance level of $p \leq 0.05$ was set a priori and used throughout. Statistical analysis was carried out using R statistical software (R Core Team). One-way analysis of variance (ANOVA) was used to analyse between-group (high, moderate, low) differences in Y-balance and total LESS scores. Tukey post-hoc analyses were conducted where appropriate to compare each pair of groups, and outcomes were presented as mean difference and 95%CI. Effect sizes (ES) were calculated from estimated means from the post-hoc analyses, and corresponding standard errors, reported as Cohen's d, and classified as 'small' (>0.20), 'medium' (>0.60), or 'large' (>1.2) (Cohen, 1988).

4.3 Results

Descriptive statistics are presented in Table 4.2. Participants were grouped as 'high' (n=11), 'moderate' (n=13), and 'low specialised' (n=11). There were no significant differences in age (p=0.33), height (p=0.38), body mass (p=0.14), or maturation offset (p=0.12) among groups. The high group had been specialised for an average of 2.0 ±1.2 years, and the moderately and low specialised groups were participating in an average of 2.4 ±1.4 and 2.1 ±0.8 sports, respectively.

Table 4.2: Summary descriptive data (mean and 95%CI)

	Low specialised	Moderately specialised	High specialised	p-value
Age (years)	10.2 (9.5–10.9)	10.5 (9.9–11.2)	9.8 (9.2–10.5)	0.33
Height (m)	1.40 (1.35–1.45)	1.45 (1.41–1.49)	1.40 (1.35–1.45)	0.21
Body mass (kg)	33.1 (28.0–38.2)	40.0 (35.3–44.7)	36.0 (30.9–41.1)	0.14
Maturation offset (years)	-2.6 (-3.1– -2.2)	-2.1 (-2.5– -1.6)	-2.6 (-3.1– -2.2)	0.12
Years playing football	5.0 (4.1–5.9)	6.2 (5.4–7.1)	5.1 (4.2–6.0)	0.08

There were no significant differences in the left (p=0.27) or right (p=0.66) absolute reach distances during the Y-balance test (Table 4.3). There was a significant difference in relative reach distance on the left leg (p=0.02). Post-hoc analysis showed significantly greater left relative reach in the highly specialised group compared to the moderately specialised group (mean diff=10.9%LL; 95%CI=2.2–19.6; p=0.01; ES=1.3), but not the low specialised group (mean diff=5.0%LL; 95%CI=-4.0–14.1; p=0.36; ES=0.59). There was no significant difference between the moderate and low specialised groups (mean diff=5.8%LL; 95%CI=-2.9–14.5; p=0.24; ES=0.68). Right leg relative reach (p=0.11), absolute (p=0.60) and percentage (p=0.46) asymmetry were not significantly different between groups.

Table 4.3: Between-group comparisons of Y-balance test and LESS total score performance (mean and 95%CI)

	Low specialised	Moderately specialised	High specialised	p-value
Absolute reach right (cm)	53.1 (49.7–56.6)	53.4 (50.2–56.6)	55.1 (51.7–58.6)	0.66
Absolute reach left (cm)	54.0 (50.5–57.4)	51.9 (48.7–55.1)	55.7 (52.2–59.2)	0.27
Relative reach right (%LL)	73.2 (67.7–78.8)	70.5 (65.4–75.6)	78.6 (73.0–84.1)	0.11
Relative reach left (%LL)	74.5 (69–80)	69.2 (63.8–73.5)	79.6 (74.3–84.9)	0.02*
Absolute asymmetry (cm)	3.38 (2.21–4.56)	2.79 (1.71–3.87)	2.58 (1.40–3.76)	0.60
Percent asymmetry (%)	6.48 (4.29–8.67)	5.24 (3.22–7.25)	4.60 (2.42–6.79)	0.46
LESS total score	7.20 (5.58–8.82)	7.75 (6.27–9.23)	5.00 (3.29–6.71)	0.05*

*=significant difference between the three groups(p≤0.05)

There was a significant difference in total LESS score between groups (p=0.05; Table 4.3). Post-hoc analysis showed fewer errors in the highly specialised group, compared to the moderately (mean diff= 2.75 errors; 95%CI= 0.05–5.48; p=0.05; ES=1.1), but not the low specialised group (mean diff= 2.20 errors; 95%CI= -0.65–5.05; p=0.15; ES=0.88). There was no significant difference between the moderate and low specialised groups (mean diff= 0.55 errors; 95%CI= -2.11–3.21; p=0.87; ES=0.22). The highest frequency of poor LESS classification was observed in the moderate specialisation group, and the lowest in those who were highly specialised. The greatest frequency of excellent and good scores were also shown in highly specialised players (Table 4.4), indicating this group displayed greater competency in the DJ task.

Table 4.4: Categorisation of LESS performance by specialisation level

	Low specialised (n=10)	Moderately specialised (n=12)	High specialised (n=9)
Excellent (0-3 errors)	1	0	2
Good (4-5 errors)	3	2	4
Moderate (6 errors)	1	0	1
Poor (≥7)	5	10	2

Counts of individual errors between groups showed little difference for most criteria (Table 4.5.). The most obvious difference was seen in 'knee flexion displacement' where fewer high specialised players (n=0) received an error (indicating they exhibited a greater range of knee flexion throughout their landing), than the moderate (n=9) or low specialised (n=5) groups. Similar differences are seen in joint stiffness and overall impression.

Table 4.5: Counts of errors scored in individual LESS criteria by specialisation level (n and %)

	Low specialised (n=10)	Moderate specialised (n=12)	High specialised (n=9)
Knee flexion initial contact	2 (20%)	2 (17%)	2 (22%)
Hip flexion initial contact	0 (0%)	0 (0%)	0 (0%)
Trunk flexion initial contact	5 (50%)	5 (42%)	2 (22%)
Ankle plantar flexion initial contact	1 (10%)	0 (0%)	0 (0%)
Medial knee position initial contact	2 (20%)	1 (8%)	2 (22%)
Lateral trunk flexion initial contact	3 (30%)	5 (42%)	3 (33%)
Stance width wide	0 (0%)	0 (0%)	0 (0%)
Stance width narrow	5 (50%)	6 (50%)	4 (44%)
Foot position external rotation	3 (30%)	4 (33%)	2 (22%)
Foot position internal rotation	1 (10%)	1 (8%)	0 (0%)
Symmetric initial contact	4 (40%)	4 (33%)	1 (11%)
Knee flexion displacement	5 (50%)	9 (75%)	0 (0%)
Hip flexion displacement	2 (20%)	2 (17%)	0 (0%)
Trunk flexion displacement	6 (60%)	7 (58%)	4 (44%)
Medial knee displacement	7 (70%)	8 (67%)	6 (67%)
Joint displacement (stiff)	4 (40%)	8 (67%)	1 (11%)
Overall impression (poor)	4 (40%)	8 (67%)	2 (22%)

4.4 Discussion

The aim of this study was to investigate if differences exist in the movement competency of pre-pubertal football players based on their level of specialisation. Given the most commonly reported age threshold for a classification of 'early' specialisation is 12 years (LaPrade et al., 2016), all highly specialised players in this study would be considered 'early specialised'. Improved jump-landing strategies were observed in those who were highly specialised, with most players graded as 'excellent' or 'good'. Highly specialised players also displayed landing strategies associated with reduced injury risk and better Y-balance left leg normalised reach distances. Cumulatively, these findings indicate that pre-pubertal players who are highly specialised, may develop improved jump-landing mechanics and enhanced dynamic stability.

The Y-balance test is an indicator of dynamic balance and active mobility (Plisky et al., 2009; Read et al., 2020). Anterior reach asymmetries have previously been associated with an increased risk of lower limb injury (Plisky et al., 2006; Smith et al., 2015). Relative reach distance is often used in preference to absolute distance due to variations in limb length between players. In this study, the highly specialised players had better relative reach on the left leg than the moderately specialised players. Additionally, while not statistically significant, based on the estimated difference and 95%CI (mean diff=8.1%; 95%CI=-1.0–17.1), it is more likely than not that they also had better relative reach on the right leg. These results are contrary to previous evidence in older aged, specialised youth, where no differences in reach distance based on level of specialisation were found (Miller et al., 2017). These participants were likely post-PHV, while the participants in our study were all pre-PHV, which may explain the difference in results (Read et al., 2020). Age- and maturation-related improvements in balance and postural control are expected in active youths (Nolan et al., 2005; Read et al., 2020). In our younger (pre-PHV, early specialised) players, increased exposure to activities requiring single-leg balance (such as kicking a ball) may have led to earlier adaptation and stability in unilateral activities, and thus improved performance in those who were highly specialised. Although there were no significant differences in anterior reach asymmetry between groups, the estimated asymmetries for all groups have the potential to exceed 4cm. This is worthy of note given asymmetry of 4cm or higher in the anterior direction has previously been associated with an increased risk of lower limb injuries in high school athletes, and thus should be considered in designing training programmes to reduce these between-limb differences (Plisky et al., 2006; Smith et al., 2015).

Previous research has shown an increased risk of ACL injury in youth football players displaying inferior landing mechanics characterised by a higher LESS score (Padua et al., 2015). Contrary to previous research in specialised youth athletes (Beese et al., 2015; DiStefano et al., 2018), the results of our study suggest highly specialised junior (pre-PHV) football players exhibit fewer errors when performing a drop jump landing than moderately specialised players. Additionally, our findings also suggest the highly specialised players had fewer errors than the low specialised players (mean diff=2.20; 95%CI=-0.65–5.05; p=0.15; ES=0.88). Previous research has shown either more errors in youth who were highly specialised (DiStefano et al., 2018), or no difference between groups of varying specialisation status (Beese et al., 2015; Peckham et al., 2018). Conflicting findings could be due to the younger, less mature participants in our study, compared with those in many of the existing studies, who were mostly post-pubertal in their mid- to late-teens (Beese et al., 2015; Peckham et al., 2018). Differences in landing mechanics have previously been observed in athletes at different chronological ages and levels of maturation (Read et al., 2018b; Read et al., 2018d).

Most football coaching in NZ at a junior (under 13) club level is conducted on a volunteer basis, meaning the quality of coaching is likely variable, with little or no formal coach education. In contrast, most if not all academy coaches would have undergone some level of coaching qualification. Typically, only when players join academies, or play at higher levels, are they exposed to coaches who may have more experience and training. Thus, many of the young footballers in the current study may have spent considerable time playing football without specific coaching on movement and skill development from a qualified professional. It has previously been suggested that highly specialised players may have better access to quality coaching, potentially greater parental support, and drive to join training academies (McGowan et al., 2020). This may explain why the highly specialised players performed better in the drop jump task. All participants in the current study were pre-PHV; however, the increased volume of structured training may have led to a synergistic adaptation in utilising the potent stimulus provided by training in players whose neural plasticity is heightened (Read et al., 2021). Muscle pre-activation and reflex control enhances with maturation, but it can also be improved through greater exposure to plyometric training (Read et al., 2021). Given the age and maturity status of this cohort, and the relatively short time the high specialised group has been focussed specifically on football, the benefit of higher-level coaching may emerge quickly (Lloyd et al., 2014; Myer et al., 2013) while the potential negative impacts of specialisation (e.g. repeated movement patterns leading to overuse) may take longer to emerge. It would be interesting to observe this cohort longitudinally to examine how movement competency develops throughout adolescence in a high specialisation sporting pathway.

The high percentage of both moderate (83%) and low (50%) specialised players exhibiting poor jump-landing mechanics is of concern due to the potential for increased risk of injury. This suggests a greater focus on foundation movement patterns is warranted in these younger ages. Previous research has shown that jump-landing mechanics in pre-pubertal youth are inferior to those post-puberty, in part due to increased strength development and muscle pre-activation in post-pubertal boys (Read et al., 2018b). Additionally, poorer landing mechanics have been observed in youths with no structured strength and plyometric-training programmes (Noyes et al., 2005). While incidence of injury associated with poor landing mechanics (e.g., anterior cruciate ligament) is low in pre-PHV cohorts, the greater neural plasticity should be considered. Training programmes commencing pre-puberty should be encouraged to optimise movement strategies later in adolescence where injury risk is higher. This also highlights the need for injury prevention programmes at community level (with limited qualified coaches), where many youth players are getting the majority of their football exposures. Programs like the FIFA 11+ have shown promising results in these environments (Gomes Neto et al., 2017). Injury prevention has been a focus for NZ Football over recent years (New Zealand Football, 2016b) which, anecdotally, has led to an increased use of the FIFA 11+. Further education programmes that target community level coaches are recommended to increase adherence which is critical to optimise effectiveness.

When evaluating the individual criteria in the LESS (Table 4.5), the main group differences were observed in 'knee flexion displacement' (i.e., the change in knee flexion angle between initial contact and maximum knee flexion). This error (i.e., reduced knee flexion) was more commonly seen in the moderately (75%) and low specialised groups (50%), compared to the high specialised group (0%). Moderate and low specialised players also recorded more errors in 'joint displacement (stiff)'. Stiffer landings are associated with decreased leg extensor strength, and lower muscle pre-activation prior to ground contact, resulting in reduced ability to attenuate ground reaction forces on landing (Cormie et al., 2010; Read et al., 2018d). It is plausible that the highly specialised players represent the better athletes and may have joined academies earlier due to their superior physical ability. Regardless, using a stiff landing strategy will result in larger ground reaction forces, and players displaying these jump strategies may be at an increased risk of injury (Pedley et al., 2020a). Targeted strength and conditioning programmes focussed on plyometric skills, and maturation-appropriate strength training considering the individual's training age and technical competency, would be considered beneficial.

The high frequency of 'poor' LESS scores in the moderately specialised group was unexpected. While it is beyond the scope of this study to provide mechanistic insights to explain this finding, it could be that the moderately specialised players were in the early stages of a specialised pathway, playing a high volume of football, all year-round, but still playing another sport. Competing in two sports concurrently can result in a high overall training load and time commitment. Players will also have decreased time available for unstructured free play, and this has previously been reported as an important contributing factor in the development of movement competency in a diverse range of skills and tasks (Barreiro & Howard, 2017; Bergeron et al., 2015).

In our study, we assessed players who were considered 'early' specialisers, involving children under the age of 12, (> -2 years pre-PHV). Most existing studies have investigated the effects of sport specialisation in participants during their mid- to late-teens, with only some including assessment or control of maturation. Including younger, pre-pubertal players allowed for the examination of potential differences that are occurring as players begin to specialise, minimising the effects of growth and maturation on movement skill. It is also a common approach in existing research to investigate sport specialisation across a range of sports (McGuine et al., 2017; Miller et al., 2017; Peckham et al., 2018); however, the effects of specialisation are likely sport specific. It may be more relevant to investigate individual sports, which we consider an additional strength of this study. The main limitation is the cross-sectional design and relatively small sample size. We observed some significant differences based on the level of specialisation, but the absence of longitudinal data means causation cannot be established. Additionally, while we have inferred some potential associations with increased injury risk based on movement strategies displayed, more research is needed to prospectively monitor sport specialisation and injuries concurrently.

4.5 Conclusion

The results of this study suggest early specialised youth football players may be more competent movers than their less specialised counterparts pre-puberty. Contrary to existing evidence, the boys that were highly specialised displayed superior movement patterns during a drop jump task and better relative anterior reach during the Y-balance test. We suggest that the improved performance in the highly specialised boys may be due to increased exposure to higher quality coaching including injury prevention programmes (e.g., FIFA 11+).

4.6 Chapter 4 Novel Contributions

In this chapter an interesting association was shown between level of specialisation and movement competency. Contrary to existing research, highly specialised young footballers displayed improved movement competency in the drop jump and the Y-balance. Additionally, the moderately specialised group displayed the poorest movement competency. This chapter also includes data to examine 'early' specialised footballers, a cohort for which there is minimal research, given most studies include older, more mature players.

Unfortunately, this chapter was highly impacted by Covid 19. Initially, this was planned as a prospective study to follow participants for a season, tracking volume and intensity of football participation, as well as injuries, and analysing changes in movement competency over the season. Covid-19 restrictions (including lockdowns) impacted my ability to conduct testing and the clubs to run training and games which resulted in this being a cross-sectional design. However, the results of this study remain impactful as these children were all pre peak height velocity (pre-PHV) and would be considered 'early specialised' by most current definitions. Additionally, due to their age, many are just starting to specialise. Thus, any differences identified are a short-term response, rather than the long-term consequences of specialisation. There is a paucity of research in these players who are at an age where they are preparing to move from the 'junior' to the 'youth' framework as guided by NZ Football. This means moving to bigger pitches and longer games where poor movement strategies may become more detrimental.

Section 3: Relationship between development pathway and movement outcomes

Overview

As part of Section 3, the development pathway of players who were post-PHV and playing at a regional representative level, was assessed. All participants were training for either the national age-group tournaments or the national youth league. While many of these players would no longer be classified as 'early' specialised based on their current age, the aim was to retrospectively assess whether there were any differences in movement outcomes based on the pathway taken (specialised vs diverse). Outcomes of interest in this section were movement competency, as well as task-specific performance outcomes including sprint and change of direction ability.

Chapter 5 Relationship between movement competency and football development pathway

5.0 Preface

Chapter 4 examined movement competency in highly specialised, pre-PHV, players. This chapter examines the preceding pathway post-PHV players took, using a retrospective survey on their sport participation since they began playing football. Movement competency was also analysed in greater detail by including single leg countermovement jumps, as well as drop jumps, and including kinetic analysis of jump landings alongside visual ratings.

5.1 Introduction

Pathways to youth sporting success have been a topic of debate in recent years. In particular, the pros and cons of sport specialisation versus a more diverse approach, also known as sport sampling. Specialisation involves purposeful, year-round participation in a single sport to the exclusion of all other sports (Bell et al., 2021; Jayanthi et al., 2013; Kliethermes et al., 2021). Sampling involves participation in multiple sports (Coté et al., 2009). It has been suggested that specialisation is needed to develop mastery of sport-specific skills and reach the elite level (Goodway & Robinson, 2015). However, there is a growing body of evidence to indicate there are no differences in performance later in life based on the development pathway, particularly in sports where peak performance occurs after physical maturation (Coté et al., 2009; Kliethermes et al., 2021).

Sport specialisation in youth has been associated with long-term negative outcomes, including increased risk of injury and lower levels of movement skill (Bell et al., 2018b; Carder et al., 2020; Jayanthi et al., 2019; Kliethermes et al., 2020; McGowan et al., 2020; Zoellner et al., 2022). Recent data from youth football indicate an association between sport specialisation and injury, even when controlling for the volume of participation (Zoellner et al., 2022). A contributing mechanism could be the increased exposure to sports-specific tasks with less recovery. This narrow focus of training has the potential to blunt motor skill development (Brenner, 2007; Brenner & Council On Sports Medicine and Fitness, 2016; Carder et al., 2020; Myer et al., 2015; Rugg et al., 2018).

Football is a sport with a high prevalence of youth specialisation (Bell et al., 2018a; Zoellner et al., 2022). It has been hypothesised that highly specialised football players might display altered biomechanics, including changes in dynamic knee alignment and lower limb loading patterns, potentially increasing injury risk (Read et al., 2016b), particularly in the lower limbs (Jones et al., 2019; Read et al., 2018a). Changes in these movements have been identified using both bilateral and unilateral jump landings (DiCesare et al., 2019a; DiCesare et al., 2019b; DiStefano et al., 2018). Conversely, these players may display greater control of body positioning in sport specific movements (Paillard et al., 2006), due to the intense focus on sport-specific training. However, lower exposure to varied movements can increase the loading of specific anatomical structures, elevating the risk of overuse injury (Carder et al., 2020). There is also a potential for greater between-limb asymmetries in strength and neuromuscular control to occur in more specialised football players due to increased exposure, with most players having a favoured kicking and stance leg (Fousekis et al., 2010). This pattern has been observed in players as young as 9-13 years (Schneider et al., 2019). While some degree of adaptation is beneficial to sport—specific performance, greater asymmetries, including in the Y-balance test, have been linked with increased injury risk (Plisky et al., 2006; Read et al., 2018c), and decreased physical performance (Bailey et al., 2013; Bell et al., 2016).Several studies have investigated the association between sport specialisation and movement competency in youth (DiCesare et al., 2019a; DiCesare et al., 2019b; Peckham et al., 2018; Root et al., 2019). The strength and direction of any relationship remains unclear, perhaps due to most studies including athletes from a range of sports (Zoellner et al., 2021). Additionally, many studies assess movement by measuring the output of specific movements rather than the strategy used (Bisi et al., 2017; Smothers et al., 2021). We propose the relationship between specialisation and movement competency is sport-specific and assessment of strategy may be more sensitive to identify differences between players in different specialisation pathways, but there is a need to examine this further. Additionally, the development pathway should be considered, rather than just whether an athlete is currently specialised or not. For these reasons, the aim of the current study was to investigate the association between football development pathways (specialised vs. diverse) and movement competency in youth football players.

5.2 Materials and Methods

5.2.1 Participants

Participants were recruited from New Zealand (NZ) youth football teams competing at a national age-group level. Sixty boys (age: 16.1 ±1.2 years; height: 1.77 ±0.07m; body mass: 66.9 ±7.5kg; maturational offset: 1.83 ±0.93 years) volunteered to participate. Approval was granted by the university's Institutional Ethics Committee prior to the commencement (Reference: 19/133). Participant assent was obtained along with parental consent for players who were under 16 years of age, while participants over the age of 16 years provided informed consent.

All playing positions were included except for goalkeepers. Participants were required to be free from lower limb injury at the time of testing, and at least six months post-peak height velocity (PHV) to minimise the effect of maturation on movement outcomes. Data collection occurred towards the end of the season and was carried out during normal training time in the late afternoon.

5.2.2 Procedures

5.2.2.1 Maturity assessment

At the beginning of the testing session anthropometric measurements were recorded, including leg length (anterior superior iliac spine to medial malleolus) (Miller et al., 2017), sitting height, standing height and body mass. These variables were then used to calculate maturation offset (Mirwald et al., 2002).

5.2.2.2 Football development pathway

Football development pathway was classified as either 'specialised' or 'diverse' based on responses to a modified version of a previously published sport history questionnaire (McGowan et al., 2020) (Appendix H). The survey took approximately 10 minutes to complete and focussed on sport specialisation and participation history (i.e., at what age they specialised and whether they played other sports in the past). Specialisation was classified based on responses to the questions 'is football more important than any other sport?', 'do you train more than 8 months of the year in football?', 'have you quit other sports to focus on football?', and 'have you only ever played football?' (Jayanthi et al., 2015). Participants were classified as 'specialised' if they responded affirmatively to three of these questions. Participants who answered ‘yes’ to two or less questions were classified as ‘diverse’. The onset of specialisation for the specialised group was defined as the number of years since the age of specialisation and calculated using the age when specialised players began training eight months or more of the year and quit other sports, i.e., the age at which they became highly specialised. The required information was determined using the sport participation history information from the questionnaire, which asked participants about their sport participation each year since they started playing football.

5.2.2.3 Movement competency measures

Movement competency measures were selected based on previous evidence that they may be influenced by sport specialisation, with a particular relevance to football (Zoellner et al., 2021). Jump landings were chosen to assess the ability to absorb landing forces, with kinematic and kinetic data included to assess strategy as well as output, both bilateral and unilateral. The Y-balance was included to assess dynamic stability, as well as due to previously reported associations between anterior reach asymmetries and injury risk (Plisky et al., 2006).

Movement competency was measured using the following tests: Y-balance anterior reach distance (absolute and relative to leg length) and reach asymmetries; single-leg countermovement jump (SLCMJ); and drop vertical jump (DJ). At the beginning of the session, tests were explained and demonstrated to the participants, and they were given time to familiarise. This involved participants each test until they could perform it appropriately, in line with the instructions given.

Drop jumps

DJs were performed from a 30 cm high box onto a force plate (AMTI, Advanced Medical Technology Inc, Watertown, MA, USA) (Figure 5.1), connected to a laptop with customised LabVIEW software (LabVIEW, Build version: 14.0, National Instruments Corp, Austin, TX, USA). Vertical ground reaction force (VGRF) was collected at 1000Hz and saved as a CSV file for later analysis. Video footage (Sony HDR-CX130 Handycam, Sony Corporation of America, New York, NY) was collected in the frontal plane, 3m from the front of the force plate at a height of 1m. Participants were instructed to keep their hands on their hips throughout the jump, drop off the box, land on the cross on the force plate (half their body height from the front of the box), and perform a maximum vertical jump (Noyes et al., 2005). The goal of the task was to minimise ground contact time and perform a maximal vertical jump immediately after landing. Three trials were completed by each participant.


Figure 5.1: Drop jump landing phase

Single-leg countermovement jumps

The force plate, camera setup and collection for the SLCMJ were consistent with the DJ.


Figure 5.2: Single leg countermovement jump landing phase

Participants stood on the force plate on one leg, hands on hips for 3 seconds, before jumping for maximum height (Figure 5.2). They were instructed to jump as high as they could and that the non-support foot could not touch the floor throughout the movement (Bettariga et al., 2022). If they used their non-support leg to help propel themselves off the ground, they were asked to repeat the trial. Three jumps were collected for each leg in randomised order.

Y-Balance

A custom-made Y-balance test kit was used, consisting of a wooden box with three poles attached in a 'y' shape (Figure 5.3). On each pole was a block that could easily slide along the pole to record reach distance. Participants stood with one foot on the wooden box with their toes behind the line on the box. They were instructed to keep their hands on hips and to push the block in the anterior direction with their other foot. They were required to keep the heel of their stance foot on the ground and avoid putting weight on the sliding block. Each participant performed three trials on each leg, in randomised order. Reach distance was measured in the anterior direction only. Anterior reach asymmetry of more than 4cm is associated with 2.5 times greater odds of lower extremity injury (Plisky et al., 2006). Absolute reach distance (cm), reach distance relative to leg length (%LL), and reach asymmetry were measured. Reach asymmetry was calculated as the absolute difference between legs (cm), and the percentage differences (absolute difference between legs/greatest reach distance*100).

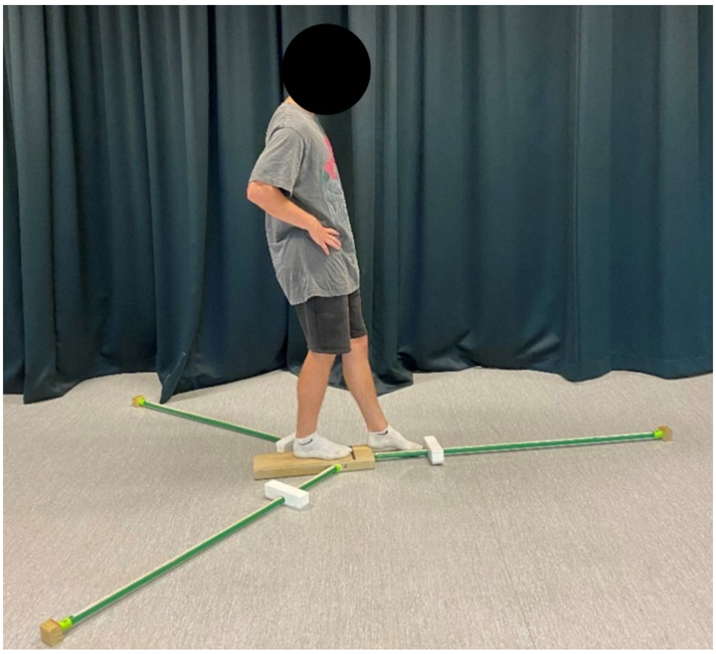

Figure 5.3: Y-Balance anterior reach

5.2.2.4 Jump landing analysis

Kinematic analysis

DJ and SLCMJ kinematics were analysed in Kinovea software (v0.9.3). The landing technique was rated using frontal plane two-dimensional video. The criteria used were based on a combination of those previously established and used for bilateral DJ landings (Padua et al., 2011; Padua et al., 2015; Rabin et al., 2018; Rabin et al., 2016). While previous visual rating systems used both sagittal and frontal plane video, restrictions on space in the current study meant that only frontal plane video was captured. Modifications were made to the rating criteria to use only frontal plane video. The criteria used in the SLCMJ were also adapted as it was a unilateral task using a previously reported visual screening of single-leg squats (Whatman et al., 2015). Landings were scored independently by two raters, both with experience in visually rating jump/landing tasks (intra-rater reliability, ICC[3,1]=0.81–0.92), and blinded to the specialisation classification of participants. Ratings were based on the predominant patterns seen in two or more of the three trials for each jump. After all jumps had been examined, scores from each rater were compared, and any differences were discussed until agreement was reached.

Table 5.1: Criteria used for rating jump landings

Criterion	DJ Rating	SLCMJ Rating
Initial contact	Toe to heel = 0 Heel to toe or flat = 1	Toe to heel = 0 Heel to toe or flat = 1
Stance width	Normal = 0 Wide or narrow = 1	N/A
Stable landing	N/A	Stick landing = 0 Hop/shuffle = 1
Frontal plane knee movement	Knees over feet = 0 Knees medial to feet = 1	Knee over foot = 0 Knee medial to foot = 1
Lateral trunk flexion	None = 0 Small to moderate = 1	None = 0 Small to moderate = 1
Overall impression	Excellent = 0 Average = 1 Poor = 2	Excellent = 0 Average = 1 Poor = 2

The five criteria rating the DJ and SLCMJs are shown in Table 5.1. Drop jumps were scored based on the lowest performing leg (Padua et al., 2011), and SLCMJs were rated individually for each leg. Participants were also given an overall score for each jump (DJ, SLCMJ left, SLCMJ right) based on the sum of errors and categorised as 'good' (0-3 errors) or 'poor' (≥4 errors).

Kinetic analysis

Jump height, reactive strength index (RSI; modified in SLCMJ), peak vertical ground reaction force (vGRF), concentric and eccentric impulse, and vertical stiffness (DJ only) were calculated from the kinetic data. Raw force data were filtered using a fourth-order Butterworth filter with a 30Hz cut-off frequency (Read et al., 2022). Kinetic variable descriptions and calculations are displayed in Table 5.2.

Table 5.2: Kinetic variable descriptions

Task	Variable	Calculation
DJ	Contact time (s)	Time between >15N and <15N
	Jump height (m)	Flight time^2 * (g/8)
	RSI	Jump height/Ground contact time
	vGRF first landing (N)	Largest vertical force value recorded during first ground contact
	Concentric impulse (Ns)	Area under the force-time curve between peak COM displacement and take off (point at which force drops below 15N)
	Eccentric impulse (Ns)	Area under the force-time curve between first landing (point at which force is greater than 15N) and peak COM displacement
	Vertical stiffness (kN/m)	-1 * ((Peak landing force/1000)/peak COM displacement)
SLCMJ	Jump height (m)	Takeoff velocity^2/(2*9.81)
	RSI (mod)	Jump height/time to take off
	Peak landing force (N)	Largest vertical force recorded after landing
	Concentric impulse (Ns)	Area under the force-time curve from the end of the braking phase to take-off (defined as the point at which the force drops below 10N).
	Eccentric impulse (Ns)	Area under the force-time curve from the end of the unweighting phase (vGRF equal to bodyweight) to the end of the braking phase (velocity equals zero).

G=acceleration due to gravity (9.81ms^{-2}); COM= centre of mass; vGRF=vertical ground reaction force; RSI= reactive strength index; mod= modified

SLCMJ movement onset was defined as the first point where force moved five standard deviations (SD) below bodyweight (Chavda et al., 2018). DJ contact time was defined as the period between the first instance where vGRF is greater than 15N (start of ground contact) until it drops below 15N again (end of ground contact) (Pedley et al., 2020b).

5.2.3 Statistical analyses

Demographic factors were compared between groups using t-tests. The association between each movement outcome with development pathway (specialised, diverse) and years specialised were analysed using a series of linear mixed models (separately for each movement outcome). For group comparisons, pathway, and trial (1, 2, 3) were treated as fixed effects, and participant was specified as a random intercept. Estimated group means, mean differences, and 95%CI were presented for each variable. All models were fit in R (R Core Team) using the *lme4* package. Estimated means, mean differences and 95%CI were calculated using the *emmeans* package and differences between groups were expressed as effect sizes (ES). ES were calculated from estimated means and corresponding standard errors, reported as Hedge's g and classified as small (>0.20), medium (>0.50), or large (>0.80) (Cohen, 1988).

For each movement outcome, a second model was fit by including years specialised, age, and trial (1, 2, 3) as fixed effects, and participant as random intercept. Regression coefficients and 95%CI were presented for each variable. Finally, differences in the proportion of each group categorised as having good versus poor landing technique were analysed using Chi-square tests. The significance level was set at $p \leq 0.05$ a priori.

5.3 Results

Fifty-four participants were included in the analysis (n = 37 specialised; n = 17 diverse). No significant differences were observed between groups for anthropometrics, maturation status, the age football participation started, and number of sports played (Table 5.3). Specialised players had been specialised for 2.9 (95%CI = 2.4–3.3) years.

Table 5.3: Group anthropometrics, maturation status and football background descriptive statistics (mean and 95%CI)

	Specialised	Diverse	Difference	p-value	Hedge's g
Age (years)	16.2 (15.8–16.6)	15.8 (15.3–16.4)	0.3 (-0.4–1.1)	0.35	0.18
Height (m)	1.77 (1.75–1.79)	1.78 (1.75–1.81)	-0.02 (-0.05–0.03)	0.54	-0.12
Weight (kg)	66.9 (64.4–69.4)	66.9 (63.3–70.6)	-0.01 (-4.46–4.44)	0.99	-0.00
Maturation offset (years)	1.88 (1.57–2.19)	1.74 (1.28–2.19)	0.14 (-0.41–0.69)	0.61	0.10
Age started football (years)	5.27 (4.72–5.82)	5.06 (4.25–5.86)	0.21 (-0.76–1.18)	0.66	0.08
Number of sports	3.16 (2.51–3.81)	3.81 (2.87–4.78)	-0.66 (-1.82–0.50)	0.26	-0.22

5.3.1 Movement competency

No significant differences between specialised and diverse groups were observed in DJ, SLCMJ, or Y-balance performance outcomes (Table 5.4). In the DJ significant differences were observed based on years specialised (Table 5.5). Jump height significantly increased by 1 cm for every additional year specialised (p=0.01) even after adjusting for age (coefficient =0.01; 95%CI= 0.001–0.016; p=0.03). RSI was also significantly greater with more years specialised (coefficient =0.08; 95%CI= 0.03–0.12; p<0.01), and again this remained significant after adjusting for age (coefficient =0.06; 95%CI= 0.01–0.11; p=0.02). The total number of errors during the DJ landing were not significantly associated with years specialised in the unadjusted model (coefficient =-0.14; 95%CI= -0.32–0.04; p=0.12) but were significantly reduced for every extra year specialised after adjusting for age (coefficient =-0.18; 95%CI= -0.37–0.00; p=0.05). No significant association was observed with years specialised and landing force, concentric or eccentric impulse, or vertical stiffness (p>0.05), even after adjusting for age.

In SLCMJ, significant associations were observed with years specialised for left leg RSI (coefficient=0.014; 95%CI= 0.000–0.028; p=0.05) and right leg eccentric impulse (coefficient=3.43; 95%CI= 0.06–6.77; p=0.05) (Table 5.5). However, after adjusting for age neither of these outcomes showed significant associations (p>0.05). Left leg landing errors were not significantly associated with years specialised in the unadjusted model (coefficient=-0.11; 95%CI= -0.25–0.04; p=0.14). However, the age-adjusted model showed a significant negative association, where more years specialised meant fewer errors were exhibited (coefficient=-0.19; 95%CI= -0.32–-0.05; p=0.01). No association was seen with years specialised and left leg eccentric impulse or peak landing force, right leg jump height, RSI, or peak landing force, or any asymmetries ($p>0.05$).

Y-balance absolute and relative reach on both legs and asymmetry were not significantly associated with years specialised.

Results for individual jump landing criteria are reported in Table 5.6. The biggest differences between groups are seen in the overall impression, which was expected given overall impression is influenced by the other factors being rated. Differences among other criteria were varied, with a lower proportion of specialised players exhibiting lateral trunk flexion, but a greater proportion exhibiting frontal plane knee movement in SLCMJ but not DJ.

Table 5.4: Between group analysis of movement variables (mean and 95%CI)

Task			Specialised	Diverse	Difference	p-value	Hedge's g
Drop Jump	Jump height (m)		0.29 (0.27-0.31)	0.27 (0.25-0.29)	0.02 (-0.01-0.05)	0.13	0.28[a]
	RSI		1.13 (1.01-1.25)	0.99 (0.83-1.14)	0.15 (-0.05-0.34)	0.14	0.31[a]
	vGRF first landing (N)		3082 (2789-3375)	2911 (2526-3297)	170 (-313-655)	0.89	0.15
	Concentric impulse (Ns)		249 (234-264)	254 (234-273)	-5.1 (-29.7-19.6)	0.47	-0.09
	Eccentric impulse (Ns)		240 (224-255)	246 (226-266)	-6.4 (-31.6-18.6)	0.49	-0.11
	Vertical stiffness (kN/m)		18.3 (15.1-21.6)	15.5 (11.2-19.8)	2.8 (-2.6-8.2)	0.51	0.23[a]
	Landing errors		1.38 (0.97-1.79)	1.69 (1.06-2.32)	-0.31 (-1.06-0.44)	0.41	-0.16
Single Leg CMJ	Jump height (m)	Right	0.16 (0.14-0.17)	0.15 (0.14-0.17)	0.01 (-0.02-0.03)	0.24	0.12
		Left	0.16 (0.15-0.17)	0.14 (0.13-0.16)	0.02 (-0.00-0.03)	0.09	0.38[a]
		Asymmetry (%)	12.2 (7.4-16.9)	18.2 (12.3-24.1)	-6.1 (-13.7-1.5)	0.11	-0.37[a]
	RSI	Right	0.17 (0.14-0.20)	0.15 (0.12-0.19)	0.02 (-0.03-0.06)	0.48	0.19
		Left	0.19 (0.15-0.22)	0.15 (0.11-0.19)	0.04 (-0.01-0.09)	0.12	0.36[a]
		Asymmetry (%)	24.4 (12.8-36.1)	24.7 (10.3-39.1)	-0.28 (-18.8-18.2)	0.98	-0.01
	Peak landing force (N)	Right	3175 (2607-3742)	3245 (2539-3950)	-70 (-976-836)	0.40	-0.04
		Left	3540 (2997-4083)	3257 (2585-3930)	283 (-581-1147)	0.44	0.15
		Asymmetry (%)	22.3 (14.0-30.6)	13.9 (3.6-24.2)	8.4 (-4.8-21.6)	0.20	0.30[a]
	Concentric impulse (Ns)	Right	115 (108-122)	116 (108-125)	-1.3 (-12.3-9.8)	0.55	-0.05
		Left	117 (110-125)	112 (103-121)	5.1 (-6.8-17.0)	0.37	0.21[a]
		Asymmetry (%)	6.3 (3.1-9.5)	7.9 (4.1-11.7)	-1.6 (-6.5-3.3)	0.52	-0.16
	Eccentric impulse (Ns)	Right	39.7 (32.4-47.0)	32.5 (23.4-41.6)	7.2 (-4.4-18.9)	0.86	0.29[a]
		Left	36.1 (29.1-43.1)	38.9 (30.2-47.6)	-2.8 (-14.0-8.34)	0.52	-0.12
		Asymmetry (%)	8.8 (1.3-16.3)	2.9 (-6.4-12.2)	5.9 (-6.0-17.8)	0.32	0.23[a]

	Landing errors	Right	1.79 (1.39-2.18)	2.00 (1.45-2.55)	-0.21 (-0.89-0.47)	0.53	-0.13
		Left	2.09 (1.74-2.44)	2.35 (1.86-2.84)	-0.26 (-0.87-0.34)	0.39	-0.17
Y- Bal	Absolute reach (cm)	Right	59.4 (57.4–61.4)	58.1 (55.2–61.1	1.2 (-2.3–4.8)	0.87	0.13
		Left	59.9 (58.1–61.6)	58.8 (56.1–61.4)	1.1 (-2.1–4.3)	0.40	0.13
		Asymmetry (%)	3.44 (2.56-4.33)	2.67 (1.37-3.97)	0.78 (-0.79-2.35)	0.32	0.19
	Relative reach (%LL)	Right	63.7 (61.8–65.6)	61.5 (58.7–64.3)	2.2 (-1.1–5.6)	0.48	0.26[a]
		Left	64.3 (62.5–66.1)	62.1 (59.5–64.7)	2.2 (-1.0–5.4)	0.14	0.27[a]
		Asymmetry (%)	5.54 (4.01-7.08)	4.40 (2.14-6.66)	1.14 (-1.59-3.88)	0.41	0.16

RSI= reactive strength index; vGRF= vertical ground reaction force; %LL= percentage of leg length; [a]=small effect size (ES); [b]=medium ES; [c]= large ES

Table 5.5: Association of movement variables with time specialised

Task			Unadjusted coefficient (95% CI)	p-value	Adjusted[#] coefficient (95% CI)	p-value
Drop Jump	Jump height (m)		0.01 (0.003–0.019)	**0.01***	0.01 (0.001–0.016)	**0.03***
	RSI		0.08 (0.03–0.12)	**<0.01***	0.06 (0.01–0.11)	**0.02***
	vGRF first landing (N)		80.5 (-38.2–198.6)	0.19	44.0 (-75.1–162.7)	0.48
	Concentric impulse (Ns)		1.49 (-4.44–7.43)	0.63	0.05 (-6.03–6.12)	0.99
	Eccentric impulse (Ns)		1.62 (-4.45–7.68)	0.61	-0.20 (-6.33–5.92)	0.95
	Vertical stiffness (kN/m)		0.57 (-0.74–1.87)	0.40	0.30 (-1.05–1.65)	0.67
	Landing errors		-0.14 (-0.32–0.04)	0.13	-0.18 (-0.37–0.00)	**0.05***
Single Leg CMJ	Jump height (m)	Right	0.004 (-0.001–0.010)	0.13	0.003 (-0.002–0.009)	0.26
		Left	0.005 (-0.000–0.009)	0.07	0.003 (-0.001–0.008)	0.15
		Asymmetry	-0.83 (-2.77–1.11)	0.39	-0.46 (-2.45–1.53)	0.27

	RSI	Right	0.007 (-0.006–0.019)	0.31	0.005 (-0.008–0.017)	0.48
		Left	0.014 (0.000–0.028)	**0.05***	0.012 (-0.002–0.026)	0.10
		Asymmetry	0.45 (-4.16–5.07)	0.84	1.09 (-3.71–4.71)	0.60
	Peak landing force (N)	Right	100.8 (-137–339)	0.42	71.0 (-172–314)	0.58
		Left	97.6 (-126–322)	0.40	73.8 (-156–304)	0.54
		Asymmetry	1.95 (-1.35–5.26)	0.24	2.45 (-0.93–5.90)	0.25
	Concentric impulse (Ns)	Right	3.05 (-0.28–6.36)	0.08	1.99 (-1.15–5.12)	0.23
		Left	2.63 (-0.06–5.32)	0.06	1.97 (-0.70–4.64)	0.16
		Asymmetry	0.36 (-0.84–1.55)	0.55	0.68 (-0.51–1.87)	0.13
	Eccentric impulse (Ns)	Right	3.43 (0.06–6.77)	**0.05***	3.08 (-0.33–6.49)	0.09
		Left	-0.26 (-3.51–2.97)	0.88	-0.53 (-3.84–2.77)	0.76
		Asymmetry	21.1 (-8.2–50.4)	0.15	23.1 (-7.7–53.9)	0.32
	Landing errors	Right	-0.10 (-0.26–0.07)	0.24	-0.16 (-0.32–0.01)	0.06
		Left	-0.11 (-0.25–0.04)	0.14	-0.19 (-0.32–-0.05)	**0.01***
Y-Bal	Absolute reach (cm)	Right	-0.07 (-0.98–0.85)	0.89	-0.18 (-1.12–0.76)	0.71
		Left	0.03 (-0.78–0.84)	0.94	-0.02 (-0.86–0.82)	0.96
		Asymmetry	0.04 (-0.35–0.44)	0.82	0.02 (-0.39–0.43)	0.89
	Relative reach (%LL)	Right	<0.001 (-0.009–0.009)	0.99	<0.001 (-0.009–0.009)	0.98
		Left	<0.001 (-0.007–0.009)	0.81	0.001 (-0.007–0.010)	0.69
		Asymmetry	0.04 (-0.64–0.72)	0.91	0.004 (-0.71–0.72)	0.94

#=adjusted for age; *=statistically significant; RSI= reactive strength index; vGRF= vertical ground reaction force; %LL= percentage of leg length

Table 5.6: Individual jump landing criteria (n; %)

Criterion		Specialised (n=36)	Diverse (n=17)
Initial contact	DJ	0 (0%)	0 (0%)
	Right SLCMJ	0 (0%)	0 (0%)
	Left SLCMJ	0 (0%)	0 (0%)
Stance width	DJ	12 (33%)	6 (35%)
Stable landing	Right SLCMJ	5 (14%)	0 (0%)
	Left SLCMJ	5 (14%)	3 (18%)
Frontal plane knee movement	DJ	11 (31%)	7 (41%)
	Right SLCMJ	7 (19%)	2 (12%)
	Left SLCMJ	9 (25%)	3 (18%)
Lateral trunk flexion	DJ	0 (0%)	0 (0%)
	Right SLCMJ	20 (56%)	14 (82%)
	Left SLCMJ	23 (64%)	15 (88%)
Overall impression	DJ	26 (72%)	7 (41%)
	Right SLCMJ	26 (72%)	17 (100%)
	Left SLCMJ	29 (81%)	17 (100%)

%=percentage of group who displayed that error. Overall impression percentage is the percentage of the group who scored 'poor' in this criterion.

5.4 Discussion

The associations between football development pathway and movement competency were investigated in this study. There were no clear differences between the specialised and diversified groups in any of the movement outcomes. However, DJ height and RSI increased with years specialised after controlling for age, while landing errors in both the DJ and SLCMJ (left only) decreased with every year specialised. Additionally, although not statistically significant, the difference in SLCMJ (left) jump height (mean diff = 0.02m) and associated 95%CI (0.00m-0.03m) suggest specialised players displayed higher jump performance than those classified as diverse.

In the current study, limb dominance and the associated increase in exposure from sport specialisation may have been apparent. For most participants, their left leg was the preferred stance leg (93%). Specialised players spend increased time in training completing tasks more frequently with a dominant stance leg, and this may result in greater performance in unilateral tasks on the left leg (Paillard & Noé, 2006). This appeared to be the case in the current study for jumping but not for dynamic balance tasks suggesting a task dependent outcome.

The lack of difference observed between specialised and diversified players in Y-balance and jump landings is in accordance with previous research investigating specialisation in football, and across other sports (Beese et al., 2015; Peckham et al., 2018). Both the Y-balance and jump tests assess general movement characteristics that are not specific to football. While the addition of kinetic data was expected to increase the test sensitivity, the drop jump task may lack specificity to identify adaptations based on football-specific development pathways. In contrast to our findings, other studies have observed differences using the same tests where diverse youth performed better than those who specialised (across sports) (DiStefano et al., 2018; Gorman et al., 2012; Miller et al., 2017). Conflicting findings between studies reinforces the need for standardisation, including methods to classify specialisation and a battery of movement competency assessments to allow comparisons to be made. There may also be benefit in sport specific assessments to allow greater task specificity. Further, measurement of strategy (especially in tasks such as the Y-balance) may also be warranted to not only quantify a movement, but also characterise it and examine the potential for mechanistic differences (Hart et al., 2019).

We and others hypothesised that specialisation in a single sport may lead to different movement strategies in youth athletes, compared to those that follow a diverse pathway (Lloyd et al., 2016; Myer et al., 2015; Read et al., 2016c). However, our results contrast with the findings of previous research, which showed that diverse sports participation leads to improved jump landing strategies (DiCesare et al., 2019a; DiStefano et al., 2018). Differences in pathway definitions, and/or movement assessments, may explain the divergence between studies; however, they may also be due to variations in training structures and/or volume in different countries. The specialised group in our study had all been exposed to other sports at a younger age (Table 5.3). Additionally, bilateral jump landings are an integral component of football-specific injury prevention and this approach has been widely adopted in most youth programmes in NZ (New Zealand Football, 2016b; Pomares-Noguera et al., 2018). Due to increased exposure to these programmes, the specialised players may exhibit increased control in jump landing movements (Paillard & Noé, 2006; Paillard et al., 2006). Similarly, an improved landing strategy on the left leg during the SLCMJ in specialised players may be due to more training/game exposure, given the left leg is the more common stance leg (Fousekis et al., 2010). However, it should be noted that the associations with years specialised are small, and thus the practical implications may be limited.

While there were no significant group differences, associations were observed between the number of landing errors and the years specialised. Players who were specialised recorded less errors in both DJ landing and SLCMJ on the left leg, for every year specialised. The DJ analysis also indicated that for every year specialised, jump height increased by 0.01m, even after adjusting for the effect of age (p=0.03). However, these findings should be interpreted with caution as these differences were small and may lack practical significance. RSI in the DJ task also increased with years specialised (mean diff = 0.06; 95%CI=0.01–0.11; p=0.02), supporting the notion that there may be differences in movement strategy based on development pathway. RSI is a ratio of jump height and ground contact time, and characterises an athlete's ability to rapidly transition from an eccentric to concentric contraction during ground contact (Lloyd et al., 2012). Based on the group mean, a yearly increase in RSI of 0.06 could represent an approximate 30% increase per year specialised. Greater RSI scores are associated with improved acceleration, COD and jump performance (Bishop et al., 2021; Young et al., 2015). Therefore, these associations between RSI and years specialised could have practical significance to the performance of youth footballers.

The results of this study indicated that meaningful differences between specialised and diverse players in movement outcome are not apparent. These results were unexpected, given the literature tends to support a diverse pathway for optimal movement development (DiStefano et al., 2018; Murata et al., 2022; Triplett et al., 2018); however, much of this is heavily based on theory with a need for more data to support it. The players from this cohort had been specialised for approximately 3 years. Based on previous evidence, we could have expected players who have followed a specialised pathway to have increased movement control in sport-specific movements (Paillard & Noé, 2006). Alternatively, diverse athletes may be expected to display greater broad movement competency due to more varied movement exposure and development (Murata et al., 2022; Myer et al., 2016). Neither of these is clearly seen in the results of the current study, so the pathway may not be important for the tests included in the specific cohort of this study. Results may vary in different cohorts and/or locations, with players exposed to different coaching and training contexts. However, there are still some results (i.e., the differences in landing errors, RSI, and potential differences between dominant and non-dominant legs) that suggest it may be useful to investigate movement strategies across a broader range of assessments, considering other variables that more clearly examine strategy.

Potential differences, or lack thereof, could also be attributed to the geographical location of the club/individual in question. Youth football development pathways in different countries will depend on the funding available. For example, in the United Kingdom (UK) there is a well-established, highly funded academy system for youth football, the Elite Player Performance Plan (English Premier League, 2011). As previously mentioned, players within this academy system likely benefit from higher educated and better resourced coaching (English Premier League, 2011). In NZ, while football is popular, the youth football pathway is not as well established nor as well funded. However, NZ Football-affiliated clubs follow a framework designed to give clear pathways to all youth (13–19 years), regardless of playing level (New Zealand Football, 2016b). Recommendations for training and matches vary depending on the age and level of the player. Talented players are encouraged to take ownership of preparation themselves, arriving early to training to perform the FIFA 11+. Volume recommendations include a maximum of five football-specific contacts per week (maximum two matches, the rest training), plus a maximum of two strength and conditioning sessions per week (New Zealand Football, 2016b). This differs significantly from the guidelines in the UK academy system where players at age 12 are expected to play a much higher volume of football-specific training (minimum 12 hours per week in category 1 academies) (English Premier League, 2011). These differences could plausibly result in different movement, performance, and injury outcomes for specialised youth footballers in each country.

A strength of the current study is that we investigated movement strategy in jump tasks as well as performance outcomes. Additionally, we attempted to control for maturation and investigate the duration of time players had been specialised for. Furthermore, all participants in the current study were playing at the same level to enable analysis of the independent association of specialisation on movement competency. Limitations of this study include the sample size, which was limited by player availability. Additionally, the cross-sectional design prevents us from assessing causation, meaning we cannot say whether differences were present before specialisation.

There were confounding factors that may have influenced our ability to draw clear conclusions from these results. While the specialised players were only involved in football at the time of data collection, most had participated in other sports previously, and there was no significant difference in the number of sports played between groups (Table 5.3). This means that the specialised players had also been exposed to more diverse, varied movement patterns which may have enabled them to develop a broad range of movement capabilities before building on these with football-specific skills once becoming specialised. Longitudinal tracking of players who start at the same level, then progress down different pathways is needed to fully understand how these pathways influence movement development. Testing at multiple time-points to track movement development is the only way to determine how changes in movement strategy emerge throughout the different pathways.

5.5 Conclusion

The aim of this study was to investigate the association between football development pathway and movement competency. There were no differences in movement competency between currently specialised or diversified football players. Jump height, RSI, and the number of landing errors did improve with years of specialisation, although most improvements were small and may not be practically meaningful.

5.6 Chapter 5 Novel Contributions

This chapter furthers knowledge by investigating movement strategy including kinetics and kinematics across a range of tasks and is one of few studies to account for the maturation status of participants. In this chapter associations with the amount of time players had been specialised were identified. This finding is novel as analysis of this type is not commonly included in the existing literature. In the absence of longitudinal data, these data may provide a useful start point to elucidate how specialisation may affect the various movement outcomes.

Chapter 6 Does specialisation impact sprint and change of direction performance in youth football players?

This chapter comprises the following manuscript which has submitted to *European Journal of Sport Science* and formatted accordingly:

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6.0 Preface

The focus of this chapter was to examine the potential differences in task-specific performance outcomes following participation in either a specialised or diverse development pathway. One of the common reasons given for youth to specialise is to increase their chances of future performance. This, alongside the results of Chapter 4, which showed that early specialised players performed better in movement tests, provided the incentive to examine if differences in performance during key match related actions (sprint and change of direction speed) are evident in specialised or diverse players. Additionally, given the results from Chapter 5, it could be hypothesised that players who follow a specialised pathway might have different movement strategies. This was a focus of the current study.

6.1 Introduction

Football is one of the most popular youth sports across the world, and the highest participation youth team sport in New Zealand (NZ) (Sport NZ, 2021). Youth football pathways into elite teams can be considered as either specialised (focused, intentional, year-round involvement in a single sport (Bell et al., 2021)), or diversified (exposure to a variety of seasonal sports (Côté et al., 2007)). A recent study indicated up to 48% of youth players in NZ were classified as highly specialised (Zoellner et al., 2022). A single sport focus potentially limits exposure to, and development of, a broad variety of movement patterns and motor skills. Players often start on a specialised pathway, when joining football academies, before or during adolescence (Murata et al., 2022). Training load and intensity increase in these environments, and participation in other sports is often restricted. While involvement in an academy is associated with an increased chance of selection for major professional teams (Huijgen et al., 2014), there is little evidence to suggest that specialising earlier (i.e. at a younger age) leads to enhanced performance or future success (Kliethermes et al., 2020). Conversely, studies investigating specialisation across multiple sports have shown an increased risk of negative outcomes, including impacts on movement competency (Murata et al., 2022), injury, burnout and dropout (Lloyd et al., 2015b; McGowan et al., 2020).

Football performance can be split into three domains: career-specific (e.g., level of achievement), task-specific (e.g., sprint speed, agility), and sport-specific (e.g., technical and tactical skills, shooting accuracy, and pattern recognition). Specialisation has been shown to benefit career-specific performance in adulthood, with male professionals reporting more organised football exposure in adulthood than amateurs (Hornig et al., 2016). However, current evidence supports a diversified approach through childhood and early adolescence to improve the chances of achieving a higher level of play in sports such as football, where peak performance occurs after physical maturation (Kliethermes et al., 2020; Murata et al., 2022). Adult football players who achieve elite-level career-specific performance also tend to specialise at a later age than those who did not achieve the same level of competition (Hornig et al., 2016). This suggests a diversified pathway throughout childhood and adolescence may be more beneficial for football career development; however, there is little evidence as to the mechanisms underlying this benefit.

Task-specific performance in football includes relevant athletic/physical competencies including cardiovascular fitness, jump landing technique, power, sprint speed and change of direction (COD) ability. It has been suggested that a diversified pathway promotes exposure to a broader range of movement patterns, and thus enhances movement competency (Salin et al., 2021). Therefore, it would be expected that specialised players display inferior task-specific physical performance compared to diversified players, when matched for the level of competition. This has been observed previously where boys who followed a diversified pathway were superior, in assessments of cardiovascular fitness, muscular endurance (Fransen et al., 2012), and jump distance (DiStefano et al., 2018; Fransen et al., 2012) to boys who specialised in a single sport (across a range of sports) (Fransen et al., 2012).

Sprint and COD performance are key physical determinants of success in football (Coelho E Silva et al., 2010; Huijgen et al., 2014). Exposure to different sports has been associated with alterations in movement strategy in these tasks (Fransen et al., 2012; Jayanthi et al., 2019). Within sprint tasks, athletes may display differences in mechanical efficiency in producing horizontal force and velocity (Morin & Samozino, 2016). Similarly, strategies used in a COD task may differ based on a player's ability to absorb braking forces and create accelerating forces (Dos'Santos et al., 2019). However, there is limited data to examine if sprint and COD performance and task completion strategy differ in youth players based on their level of specialisation (Kliethermes et al., 2020; Zibung & Conzelmann, 2013).

Cumulatively, the effects of sport specialisation on task-specific physical determinants of football performance are not well established. Thus, the aim of this study was to investigate if differences in sprint and COD performance exist between youth football players on development pathways classified as either specialised or diversified. Given the exposure to a wider range of athletic tasks, it was hypothesised that diversified players would perform better in sprint and COD tests and may display different movement strategies in both tasks.

6.2 Methods

6.2.1 Experimental approach to the problem

A cross-sectional study design was used to investigate the differences between specialised and diversified youth football players in sprint and COD performance, and task completion strategies. Institutional review board approval was granted by the University's Ethics Committee (AUTEC# 19/113), informed parental consent and participant assent were obtained prior to data collection. Participants took part in a single data collection session during their normal training time.

6.2.2 Participants

Twenty male youth outfield football players (age: 15.9 ±1.1 years; height: 174.7 ±7.1 cm; body mass: 66.0 ±8.3 kg; maturation offset: 1.5 ±0.8 years) competing at a regional level in Auckland, NZ, were recruited for this study. All players were required to be free from lower limb injury at the time of testing, and at least 6-months post-peak height velocity (PHV) to minimise the effect of maturation on performance outcomes.

6.2.3 Procedures

6.2.3.1 Participation pathway

Prior to the performance tests, participants completed a 10-question survey (McGowan et al., 2020), modified to be football-specific, to categorise their football pathway as either specialised or diversified. Questions focussed on sport participation history at each chronological age and sport specialisation. Researchers were blinded to participant group categorisation (specialised or diversified) during data collection and processing.

Participation pathway was categorised based on the player's current level of specialisation, using the responses to the questions: 'do you consider football more important than any other sport?', 'do you train more than 8 months of the year in football?', 'have you quit other sports to focus on football?', and 'have you only ever played football?'. Any participants who answered 'yes' to three of these questions were placed in the specialised group (Jayanthi et al., 2015) (n = 11; mean time specialised 3.6 ±1.7 years). All other players were allocated to the diversified group (n = 9) and were currently participating in an average of 2.0 ±0.5 sports including cricket (n=4), futsal (n=2), basketball (n=1), swimming (n=1), touch rugby (n=1), volleyball (n=1), handball (n=1), and Australian football (n=1).

6.2.3.2 Estimate of Biological Maturation

Participants' sitting and standing height and body mass were measured using a stadiometer and electronic scales (SECA 216, Germany). Seated height was taken on a 35cm box, and leg length was also measured to calculate maturation offset (Mirwald et al., 2002). With the participants standing with their weight evenly distributed, leg length was measured as the distance from the anterior superior iliac spine to the medial malleolus using a tape measure (Miller et al., 2017). The length of both legs was measured, and the mean length was used to calculate maturation.

6.2.3.3 Sprint Performance

Three 30m maximal sprints were performed with one-minute recovery between efforts. Dual-beam infrared timing gates (Swift Performance, Lismore, Australia) were positioned at 0, 10, 20, and 30m, with the start line 0.5m behind the first set of gates. A radar gun (Stalker ATS 5.0, Texas, USA) was also used, positioned 2m behind the start line, at a height of 1m. The radar was used to enable the calculation of force-velocity variables for a more in-depth analysis of sprint mechanics. Participants started when ready, to remove any reaction time effect, and were instructed to sprint maximally until passing through the final gate. Ten and 30m times were recorded.

6.2.3.4 Change of Direction Task

Change of direction speed was assessed using a 5-0-5 test (
Figure 6.1). Participants sprinted maximally to a line of cones positioned 15m from the start, turned 180 degrees, and sprinted back 5m (Cuthbert et al., 2019). Three trials were performed in each turning direction in a randomised order with one-minute rest between trials. Timing gates were positioned at the 10m mark. Total 5-0-5 completion time (time from timing gate to the cones and back) was recorded. A camera (iPhone 6, Apple Inc., USA) was used to record sagittal plane video of the 5-0-5 task. The camera was fixed to a tripod 3m to the side of the 12.5m mark, at a height of 1m.

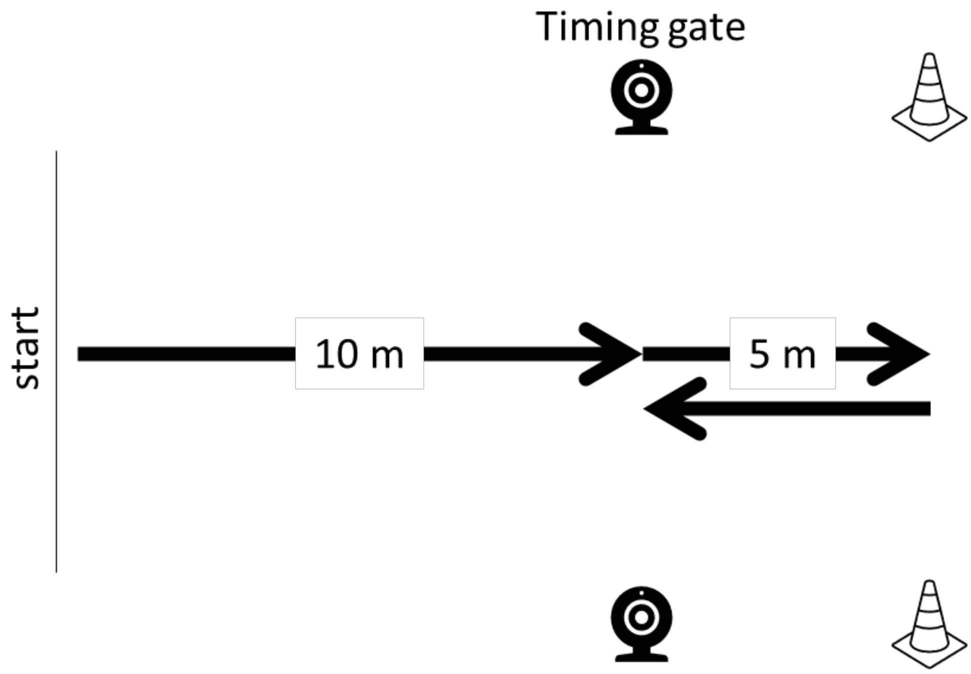

Figure 6.1: Setup for 5-0-5 agility test

6.2.4 Data processing

Radar data were processed to analyse the force-velocity profiles of participants during the sprint trials. Raw radar data were manually screened as described previously

(Simperingham et al., 2019) to: (i) delete data recorded before and after each sprint; (ii) label trials as 'acceleration runs', thus forcing the velocity-time curve to start through zero; and (iii) remove outliers on the velocity-time curve, likely caused by segmental movements of participants during sprinting. Following screening, files were imported into a custom software script (LabVIEW, Build version: 14.0, National Instruments Corp, Austin, TX, USA), which applied a validated method of estimating external horizontal force production (Morin et al., 2019; Samozino et al., 2016). Briefly, the velocity-time data from each trial were fitted with an exponential function via linear least squares regression (Furusawa et al., 1927), after which horizontal acceleration was computed via derivation of velocity over time. Horizontal force was estimated as: $F_h = m \cdot a_h + F_{aero}$; where m equated to body mass, and F_{aero} corresponded to air drag (computed using estimates of frontal area from height and weight (Arsac & Locatelli, 2002)). The ratio (RF) between the force produced horizontally and the resultant ground reaction force (equivalent to body weight over time) was computed as a representation of the technical ability to orient and apply force to accelerate (Samozino et al., 2016).

Horizontal force (F_h) data were used to compile linear force-velocity relationships, and a linear relationship between RF and velocity (Cross et al., 2017). From the force-velocity relationship, maximum theoretical horizontal force (F_0) and velocity (V_0) were computed as the intercepts of the linear regression. Maximum horizontal power (P_{max}) was calculated as $F_0 \cdot V_0/4$. Finally, the slope of both the force-velocity relationship (SF_v) and the RF/velocity relationship (DRF) were reported, with the latter corresponding to the decrease in the ratio of force with increasing velocities (Cross et al., 2017; Morin et al., 2011).

Change of direction deficit (CODD) was calculated as the time taken to complete the 5-0-5 distance minus the fastest 10m split from the 30m sprint (Nimphius et al., 2017; Nimphius et al., 2016). Given 5-0-5 time is mostly linear sprinting, with only 31% of the time spent on the actual COD, faster linear sprint times have an advantage when just examining total 5-0-5 time (Nimphius et al., 2016). The CODD allows the comparison of COD ability without being biased by differences in linear sprinting speed. This gives an indication of pacing coming into the COD task (Nimphius et al., 2017). Asymmetries in COD ability were calculated as the absolute difference between the time taken for COD in each direction (COD left-COD right), recorded as the difference in seconds and also expressed as a percentage of COD time in the fastest direction (COD left-COD right/fastest COD * 100).

Two-dimensional video data from the 5-0-5 task were analysed using open-source software (Kinovea version 0.9.5). Each trial was viewed in slow motion as many times as needed by a single researcher (Kappa= 0.59–0.70). Assessment criteria (yes/no) examined braking strategy in the penultimate foot contact via trunk inclination (was the trunk inclination in the intended direction of travel?) and heel ground contact (was there heel ground contact during the penultimate foot contact?). This was a modification (using lateral-view variables for penultimate foot contact indicators of braking strategy) of previously validated methods (Dos'Santos et al., 2019).

6.2.5 Statistical analyses

Estimated mean and 95% confidence intervals (95%CI) are reported for all data. Demographic factors were compared between groups using t-tests. A significance level of $p \leq 0.05$ was used throughout and set a priori. Between-group (specialised, diverse) differences in all continuous variables were analysed using a linear mixed model built in R (R Core Team) using the *lme4* package. 'Group' and 'trial' (1, 2, 3) were used as fixed effects, and 'participants' was specified as a random intercept. The *emmeans* package was used to calculate estimated means and differences. Dichotomous variables (backward trunk inclination and heel contact) were analysed using Chi-squared analysis. Effect sizes (ES) were calculated using estimated means and standard error, and reported as Hedges' g and classified as small (0.20-0.49), medium (0.50-0.79), or large (≥0.80) (Cohen, 1988).

6.3 Results

No between-group differences were observed for maturation offset (mean difference= 0.35 years [-0.44–1.13]; p=0.37), age (mean difference= 0.72 years [-0.27–1.7]; p=0.15), mass (mean difference= 0.49 kg [-7.56–8.54]; p=0.90), or height (mean difference= 0.68 cm [-6.21–7.56]; p=0.84).

6.3.1 Sprint Performance

There were no significant between-group differences for any sprint performance variables (Table 6.1). However, there were moderate ES in SF_V (mean difference= -0.09;

95%CI = -0.21–0.03; ES=-0.52) and DRF (mean difference= 0.01; 95%CI = -0.002–0.012; ES=0.50).

Table 6.1: Between-group comparisons of sprint variables (mean and 95%CI)

	Specialised	Diversified	Difference	p-value	Hedges' G
0-10m (s)	1.84 (1.76–1.92)	1.88 (1.79–1.96)	-0.04 (-0.15–0.08)	0.41	-0.22
0-30m (s)	4.46 (4.26–4.65)	4.56 (4.35–4.77)	-0.10 (-0.39–0.19)	0.35	-0.24
v_{max} (m/s)	7.94 (7.54–8.34)	7.85 (7.34–8.35)	0.10 (-0.55–0.74)	0.44	0.10
F_0	457 (406-509)	480 (416-545)	-23.2 (-106-59.3)	0.42	-0.20
$RelF_{max}$ (N/kg)	6.99 (6.46–7.52)	7.26 (6.59–7.93)	-0.28 (-1.13–0.58)	0.30	-0.23
SF_v	-1.22 (-1.30–-1.15)	-1.14 (-1.23– -1.04)	-0.09 (-0.21–0.03)	0.06	-0.52
P_{max}	971 (823-1119)	987 (801-1173)	-15.8 (-253-222)	0.86	-0.05
$RelP_{max}$ (W/kg)	14.8 (13.1–16.4)	14.9 (12.8–17.0)	-0.18 (-2.87–2.5)	0.84	-0.05
RF	0.48 (0.45-0.50)	0.49 (0.46-0.52)	-0.01 (-0.05-0.03)	0.53	-0.17
DRF	-0.076 (-0.080– -0.072)	-0.081 (0.086– -0.076)	0.01 (-0.002–0.012)	0.06	0.50

V_{max}= peak velocity; F_0= theoretical maximal horizontal force; $RelF_{max}$= peak relative horizontal force; SF_v= slope of force velocity curve; P_{max}= peak horizontal power; RP_{max}= peak relative horizontal power; RF= ratio of horizontal force production to ground reaction force; DRF= RF/velocity relationship

6.3.2 Change of Direction Performance

There were no significant between-group mean differences in COD performance variables and Ess were trivial (Table 6.2). The specialised group did display significantly greater asymmetry in COD total time (absolute, ES = 0.91, p=0.01 and percentage, ES = 0.90, p=0.01).

Table 6.2: Between-group comparisons of change of direction ability

	Specialised mean (95%CI)	Diversified mean (95%CI)	Difference (95%CI)	p-value	Effect size (Hedges' G)
5-0-5 Left (s)	2.49 (2.41–2.57)	2.49 (2.40–2.58)	0.00 (-0.12–0.12)	0.43	-0.0001
CODD Left (s)	1.23 (1.14–1.32)	1.22 (1.12–1.31)	0.01 (-0.12–0.14)	0.82	0.07
5-0-5 Right (s)	2.48 (2.39–2.58)	2.52 (2.41–2.62)	-0.03 (-0.17–0.11)	0.33	-0.15
CODD Right (s)	1.22 (1.13–1.32)	1.24 (1.14–1.35)	-0.02 (-0.16–0.12)	0.78	-0.09
Asymmetry (s)	0.11 (0.08-0.14)	0.05 (0.01-0.08)	0.06 (0.02-0.11)	0.01*	0.91
Asymmetry (%)	8.98 (6.46-11.51)	3.89 (1.10-6.69)	5.09 (1.32-8.85)	0.01*	0.90

*= statistically significant; CODD= change of direction deficit

There was a significantly greater frequency of backwards trunk inclination on the penultimate step turning to the left in the specialised group, than in the diverse group (difference=77% [54–99%]; p=0.01; Table 6.3.). However, there were no significant differences between groups in trunk lean turning to the right (difference=13% [-32–59%]; p=0.55; Table 6.3), or frequency of heel contact in the penultimate step (p>0.05). Additionally, we observed a greater frequency of heel contact in the specialised group when turning to the left (difference=33% [-18–83%]; p=0.21; Table 6.3). This trend was smaller and reversed when turning to the right (i.e., it was observed more often in diversified than specialised players (difference=25% [-21–71%]; p=0.30; Table 6.3).

Table 6.3: Individual change of direction strategy criteria (n; %)

Criterion		Specialised (n=11)	Diverse (n=9)
Heel contact	Right	4 (36%)	4 (44%)
	Left	6 (56%)	3 (33%)
Trunk lean	Right	8 (73%)	4 (44%)
	Left	10 (91%)	3 (33%)

% = percentage of group who displayed the error.

6.4 Discussion

The aim of this study was to investigate differences in sprint and COD performance between specialised and diversified male youth football players. Consistent with previous research there were no differences in performance outcomes (Kliethermes et al., 2020; Murata et al., 2022); however, players following a specialised pathway displayed greater asymmetries in COD speed. While not as clear, our estimates (and their uncertainty based on the associated confidence intervals) are also compatible with potential differences in sprint and COD strategy (SF_V, DRF, penultimate foot contact in COD) compared to players on a diversified pathway. Thus, specialisation may have a greater effect on task execution than performance outcome alone.

Asymmetries in COD speed have been reported previously (Bishop et al., 2021), and could effect on-field performance in football due to the need for turning proficiency in either direction. Increased asymmetry in specialised players may be due to a greater frequency of direction change actions biasing one side in certain playing positions (Bloomfield et al., 2007). In contrast, a diversified player may have had greater exposure to COD tasks in both directions, and more variance in task-specific actions. This increased variation may have reduced the magnitude of limb dominance, leading to less asymmetry. It may be beneficial to expose specialised players to different positions throughout their involvement in youth football development programmes. Additionally, specialised players may benefit from using alternate sports/activities in training, including unilateral plyometric and resistance training.

Qualitative analysis of COD task completion strategy indicated the diversified group used a more upright trunk posture at the penultimate foot contact before changing direction. This strategy has been associated with decreased efficiency in deceleration and reacceleration depending on the next direction of travel (Dos'Santos et al., 2020; Nimphius et al., 2017), but also decreased risk of knee injury (Jones et al., 2015). The combination of backwards trunk inclination and heel strike may contribute to improved performance (speed) in COD tasks (Dos'Santos et al., 2020; Dos’Santos et al., 2021); however, both have also been associated with increased braking forces (Jones et al., 2015). Thus, knee alignment and thigh eccentric strength levels are important to allow quick deceleration and avoid injury. More frequent heel contact in the penultimate foot strike was observed in specialised players when turning towards the left. In a specialised football environment, with high exposure to football-specific COD tasks in training and matches, technical approaches like modified trunk inclination may inherently be developed to optimise completion time. To our knowledge, there is no research that has examined differences in performance and technical ability in a 5-0-5 COD task between sports, but these results suggest that the strategies used by the specialised players support faster COD task completion. However, the increased braking forces associated with these strategies may lead to increased injury risk, particularly if players do not have sufficient eccentric strength to absorb them. This is of particular concern if players are put in a position (e.g., to defend in a match) where a COD is required in their weaker direction. In players who display greater asymmetries, this may result in further increases in injury risk, especially if their preferred (or only) COD strategy is one with higher braking forces. In the absence of varied movement demands and targeted strength and conditioning, these approaches should be monitored to ensure players have sufficient eccentric strength to decelerate safely and reduce the risk of injury.

Only small non-significant differences in sprint completion time between groups were shown in the current study, but more clear divergences in the strategies used to achieve these outcomes were present. Due to variations in exposure to sprint activities and drills (Haugen et al., 2019), diversified participants may utilise different sprint techniques to those seen in the specialised group who will have been exposed to a reduced number of constraints imposed by a single sport. Differences in strategy can influence sprint speed, and this was observed in the force-velocity profiles (Baumgart et al., 2018; Jiménez-Reyes et al., 2022). While not statistically significant, our estimates suggest enhanced mechanical efficiency and higher horizontal force production were more likely in the specialised players. The force-velocity curve showed an increased slope (ES= -0.52), which indicates a more force-oriented approach that may lead to improved acceleration (Jiménez-Reyes et al., 2022). The mechanical efficiency with which athletes apply horizontal force and maintain horizontal force production while increasing speed can be assessed by calculating the ratio of horizontal force to ground reaction force, and its relationship with velocity (DRF) (Morin & Samozino, 2016). Specialised players are likely to experience more short-distance sprints through higher volumes of football training and competition, and thus may have developed a more efficient strategy, which allows greater horizontal force production in a shorter time, than their diversified counterparts.

A strength of this study was the use of technical measures alongside performance outcomes to examine the task completion strategy used. A limitation was that while the tests used are relevant to football performance, they do not assess football-specific skills, which may result in differences based on development pathways. Additionally, since football performance is impacted by several other physical, physiological, and technical factors, future research may wish to examine a more diversified player profile. While the sample size was small, our data provides a preliminary indication of potential differences that may be worth investigating further. Finally, the design was cross-sectional, capturing information at a single time point. Prospective studies are needed to evaluate the development of tactical skills and physical performance through different development pathways (Kliethermes et al., 2020).

6.5 Practical Applications

Strategies used by specialised players tended to be those associated with increased efficiency in both the sprint and COD. This suggests there may be some benefit for diversified players to participate in more targeted, football-specific sprint and COD training, as well enhancing sprint and COD mechanics. Some of the strategies displayed by the specialised group (increased braking forces and asymmetries during COD) have been associated with increased injury risk and should be monitored and managed by ensuring players participate in appropriate strength and conditioning. Specific strategies should include an increased focus on eccentric leg and hip strength, unilateral strength and plyometric training, as well as varied sport and training exposure. Training should include variation in tasks (including sprint and COD) and different constraints to encourage the exploration of a greater number of movement solutions and thus support enhanced movement variability.

6.6 Conclusion

The results of this study indicate engagement in a specialised football development pathway does not lead to significantly increased sprint or COD speed in youth football players. There were differences in task completion strategy identified. Most notably, specialised players displayed greater COD asymmetry, combined with a posteriorly inclined trunk position during the penultimate foot contact. While this trunk position may decrease time taken for the COD task, it is also associated with increased braking forces and thus requires higher eccentric leg strength to control the movement safely. During sprinting, improved horizontal force production and mechanical effectiveness were also found in the players who followed a specialised pathway. The mechanisms that underpin these potential differences warrant further investigation.

6.7 Chapter 6 Novel Contributions

The results of this study are in accordance with both Chapters 4 and 5. While no statistically significant differences in the performance of either task were indicated, there was a tendency for specialised players to display more efficient movement strategies. However, asymmetries in change of direction speed were significantly greater in the specialised group. Additionally, while some of the strategies used by the specialised group are associated with increased efficiency, they may predispose players to increased injury risk if there is not sufficient strength to control the potentially higher joint forces. Differences in task completion strategy may be a contributing factor to the independent association between gradual onset injury and specialisation reported in Chapter 3.

Chapter 7 Discussion and conclusion

Many recent studies have attempted to determine the potential effects sport specialisation may have on youth athletes (Jayanthi et al., 2019; Kliethermes et al., 2020; Pasulka et al., 2017), and whether it is needed for future sporting success (Kliethermes et al., 2020; Murata et al., 2022). Despite there being no clear evidence for the need for specialisation in most sports, the prevalence remains high (Bell et al., 2018a). When specialisation occurs at a young age, it has been classified as 'early' specialisation, however there is no consensus on what age the cut-off is to define 'early'. There is some evidence that specialisation at a young age (early specialisation) is beneficial in sports where peak performance occurs prior to physical maturation (e.g., gymnastics, dance, figure skating) (Kliethermes et al., 2020). Conversely, in sports where peak performance occurs after physical maturation, such as football, there are examples of professional athletes developing via a variety of pathways. In fact, there is a growing body of evidence suggesting delaying specialisation and following a diverse, sampling pathway may be the optimal approach for sports development in many sports (Côté & Hancock, 2014; Côté et al., 2009; Murata et al., 2022; Myer et al., 2016). However, there is still little evidence as to why elite adult athletes, including footballers, are more likely to have come from a diverse sport pathway. Enhanced development of movement competency and its positive influence on both sport development and injury prevention, has been suggested as a potential mechanism to explain the benefits of sports sampling and delayed specialisation. Given the long-term effects of intense involvement in a single sport are likely sport-specific, it is important to investigate sports individually to determine the impact of specialisation. Therefore, the main aim of this thesis was to investigate the association between sport specialisation (including early specialisation) and movement competency in youth football players. This was done by answering the following questions:

1. What is the prevalence of sport specialisation in NZ youth football, and is this related to injury history?
2. What is the evidence for an association between sport specialisation and movement competency in youth sport?
3. What is the association between early specialisation and movement competency in pre-PHV youth football players?

4. What is the association between football development pathways and movement competency in youth football players?
5. What is the association of sprint and COD performance with development pathways in youth football players?

This thesis provides novel perspectives on links between sport specialisation and movement competency in NZ youth football. In line with previous research, a high prevalence of specialisation, and associated injuries, were identified in youth football in NZ (Chapter 3). The association with movement competence is more complex and varies based on the cohort, the context, definitions and tests used (Chapter 2). When considering movement competence in relation to injury risk, there is likely more consideration needed of movement strategy, rather than purely movement outcome. Chapters 4, 5, and 6 were designed to include some measure of strategy, however different tests may be needed to further investigate this. Finally, this thesis highlights the need for sport specific, and regional/context specific research when analysing the effects of sport specialisation.

The need for sport-specific research in identifying the associations between sport specialisation and movement competence has been previously reported, but this was further highlighted in Chapter 2. This thesis was the first sport-specific research on youth sport specialisation in NZ and highlighted that there is a high prevalence of specialisation (43%) in youth football in NZ, along with a high prevalence of injuries (84%; Chapter 3). The increased volume of focused sport participation, associated with specialisation, has been posited as a potential contributor to the increased injury risk (Jayanthi et al., 2015; Post et al., 2017a). However, it was found that while there were associations between volume (weekly and annual) of participation and gradual onset injuries, there is also an independent association with level of specialisation (Chapter 3). These findings are consistent with previous studies reporting specialised players were at increased risk of either all injuries (Jayanthi et al., 2015; McGuine et al., 2017) or specifically overuse injuries (Bell et al., 2018a). These studies, as well as the results from Chapter 3, highlighted the importance of this research, and the need for identification of the mechanisms contributing to the high rate of injury. Poor movement mechanics and repeated exposure to a small range of movement patterns have previously been suggested as potential mechanisms for the increased injury rate (Bell et al., 2019; Bell et al., 2018a). This supported our decision to then focus on movements associated with injury risk in Chapters 4 and 5.

The systematic review in Chapter 2 identified some of the difficulties in identifying associations between specialisation and movement competence due to the variations in tests and definitions used, as well as a need for sport-specific research. There was, however, some evidence to indicate that multi-sport athletes may demonstrate greater movement competency in jump landing mechanics (DiStefano et al., 2018; Herman et al., 2019). These findings were used to inform test selection for the following studies investigating movement competency. The review did highlight the need for sports-specific research and consideration of early specialised groups. Chapter 2 also highlighted how challenging it can be to compare studies given the large variation in methods and definitions used, which supported the need for comparative studies using similar methods and cohorts. An additional challenge was the limited number of validated, reliable tests of movement competence, particularly in youth cohorts, and the fact that most tests are designed to measure the outcome of a movement rather than underlying movement strategies. One popular assessment of movement competence that has been used across a number of sports, is the FMS (Schneider et al., 2019). However, this is a predominantly static assessment which has been suggested to have limited relevance to football players (Schneider et al., 2019). There was some evidence to indicate that multi-sport athletes may demonstrate greater movement competence in jump landing mechanics, which led to the inclusion of these tests in Chapters 4 and 5 (DiStefano et al., 2018; Herman et al., 2019). Additionally, asymmetries in the anterior reach of the Y-balance test have previously been linked to increased injury risk and have been suggested as a measure of dynamic balance (Plisky et al., 2006). Therefore, this test was including in subsequent movement testing batteries in this thesis.

Contrary to previous research, some of the findings from Chapters 4, 5, and 6 suggest superior movement outcomes in specialised youth football players in NZ. While there were a limited number of measures that had clear (significant) differences between specialisation groups, those that were different tended to support better performance outcomes in the specialised players. In previous literature, including in expert/position statements (LaPrade et al., 2016; Lloyd et al., 2016; Valovich McLeod et al., 2011), there is a suggestion that specialising in youth may limit diverse movement development.

However, closer evaluation of the evidence for differences in movement development based on level of sport specialisation (Chapter 2), reveals this is limited. Much of the existing evidence is based on expert opinion and theory, rather than practical assessment or measures. In many outcomes of this thesis, particularly in the tests where the movement output or outcome was measured, rather than the movement strategy, specialised players tended to perform better. However, when looking at movement strategy in more detail, those used by specialised players in Chapters 5 and 6 also tended to be strategies which carry a higher risk of injury.

There is no clear evidence sports specialisation is 'needed' in most sports (Kliethermes et al., 2020; Murata et al., 2022), however, this thesis supports previous research, in suggesting the prevalence remains high (Bell et al., 2018a)(Chapter 3). Furthermore, the prevalence in this cohort was higher than previously reported both in NZ (McGowan et al., 2020), and in football internationally (Bell et al., 2018a). This supports the need for both sport specific and region/context specific research, as well as consensus definitions and classification methods, as discussed in Chapter 2. Additionally, contrary to previous research (Post et al., 2017a), it was reported that boys were more likely to be highly specialised than girls. This may be because professional women's football in NZ is relatively new and thus fewer girls have long-term ambitions for professional contracts. This may change with the publicity surrounding the FIFA women's world cup in NZ and Australia.

While there are some likely differences in prevalence of specialisation in different sports and locations, the extent of differences is difficult to determine when studies use different definitions, methods and classifications (Chapter 2). A specialised player classified using different methods could differ in whether they play other sports, have ever played other sports, whether they play all year, what constitutes 'all-year', the importance they place on the main sport, among others. All of these factors have the potential to influence long-term outcomes in movement and injury. The consensus definition (Bell et al., 2021) helps to improve consistency; however, a classification method is still needed to enable consistent approaches across studies. In this thesis, classification was based on the Jayanthi 3-point scale. In most studies using the 3-point scale to classify specialisation there is a limitation in that one of the questions asks 'have you quit other sport to focus on your main sport?', to which a participant who has only ever played one sport would answer 'no', disqualifying them from being highly specialised. Arguably, this player would be more at risk of movement development deficits (and associated injury risk) than one who has played other sports but ceased participation in these to specialise in one sport. Additionally, this would result in an underestimation of the prevalence of highly specialised youth. In the questionnaire developed by (McGowan, 2018), an additional question was added to account for this, 'have you only ever played one sport?'. This was included in the classification questions used throughout this thesis and may explain the differences in prevalence between Chapter 3 and previous studies, internationally and in football.

The term 'early specialisation' was coined to describe specialisation in young athletes, but there is no consensus on what age the cut-off is to define 'early'. Current evidence suggests that elite adult athletes, including footballers, are more likely to have come from a diverse sport pathway (Bridge & Toms, 2013; Buckley et al., 2017; Ross et al., 2022). There is currently no explanation for this, but a possible contributing factor could be the slower, more manageable improvements of diverse pathways, as suggested by comparing the results of Chapters 4 and 5. Given the long-term effects of intense involvement in a single sport are likely sport-specific, it is important to investigate sports individually to determine the impact of specialisation.

Pre-PHV is a crucial time for movement development in youth, given high neural plasticity (Myer et al., 2013). This period of biological maturation also overlaps the age most associated with 'early' specialisation (Myer et al., 2015). Results from Chapter 4 showed that early specialised football players displayed greater movement competency than their less specialised peers. This was evident in both the DJ task (assessed using the LESS) and relative anterior reach in the Y-balance task. Existing research opposed these findings, suggesting that movement competency would be higher in lower specialised players (DiCesare et al., 2019a; DiStefano et al., 2018). Contrasting findings may be due to differences in training and athlete development in different countries. Much of the existing literature is based either in the UK, Europe or the USA, all of which likely have very different approaches to youth athlete development and difference structures of youth sport delivery. In NZ there is minimal, if any, exposure to strength and conditioning training, or any formal coaching regarding movement development for most youth prior to high school. This means that, particularly in pre-PHV cohorts, such as in Chapter 4, highly specialised players, may benefit from improved access to neuromuscular training. Highly specialised youth footballers have had increased exposure to neuromuscular training using the FIFA 11+ in training, and thus may have improved abilities in associated movements. Additionally, this group (Chapter 4) had been specialised in a period of high neural plasticity and may have benefitted from a higher volume of potentially higher quality coaching. Thus, these players have improved movement outcomes, while negative outcomes due to repeated movements may take longer to emerge.

Interestingly, the differences seen in Chapter 4 were no longer evident in the post-PHV cohort (Chapter 5), where there was no significant difference between the specialised and diverse groups in Y-balance performance, or the kinetic variables or visual ratings for the DJ or SLCMJ. There was a small improvement in RSI and visual ratings with each year specialised in the post-PHV cohort (Chapter 5); however, the magnitude of improvement was minimal and thus may not be practically significant. Reasons for these inconsistent findings across age groups may be due to different lengths of time specialised. The post-PHV cohort (Chapter 5) were specialised for a longer period than the pre-PHV cohort (Chapter 4), but with similar weekly volumes of organised sport to the diverse group. With time, the advantage gained by the combined greater volume of sport-specific, specialised training and high neural plasticity (observed in Chapter 4) may be lost or minimised. The benefits of diverse sport involvement on movement development may catch up over time, resulting in more even outcomes in the post-PHV cohort (Chapters 5 and 6). This may suggest that while specialising earlier may see short term benefits/improvements, diverse pathways are a slower, maybe more manageable development that allows improved long-term results. These results suggest that the physical benefits tend to be the same or similar in the adolescent years. Combined with other potential benefits of a diverse sport pathway, this may be more beneficial to long term development.

Task performance outcomes (sprint and COD) were also equivalent in specialised and diverse players (Chapter 6). However, in this post-PHV cohort, there was some evidence to indicate differences in task completion strategy between specialised and diverse players. Kinetic differences were observed in sprint performance, with specialised players displaying improved horizontal force production and mechanical efficiency. Interestingly, RSI was the variable in Chapter 5 that had the greatest (and potentially most meaningful) increase with time spent specialised. These combined results suggest that there may be an element of mechanical efficiency that is impacted by specialisation. The players who are involved in a higher volume of sport-specific training may be better able to create force in the desired direction and move efficiently. In the COD task (Chapter 6), there was also some support for this notion as the specialised players demonstrated improved technique. This was the first study to investigate potential differences in COD strategy based on specialisation in football, however differences in COD ability (as measured by COD deficit) have been previously reported in football and team sports (Loturco et al., 2018; Loturco et al., 2022). A greater proportion of specialised players demonstrated optimal trunk inclination (in the new direction of travel) in the penultimate foot contact before the COD task. This has been associated with more efficient braking and force transfer in COD tasks (Dos'Santos et al., 2020; Nimphius et al., 2017). However, it should be noted that this approach to COD tasks is also associated with increased forces going through the knee during the COD (Jones et al., 2015). High braking forces are of concern as, particularly during COD, these can increase risk of injury to structures such as the anterior cruciate ligament. Given the association with improved performance, however, the focus of interventions should be on developing sufficient strength to safely control these forces rather than suggesting decreasing the force (Fox, 2018). This and the increased COD asymmetries in the specialised group suggest that these players may benefit from targeted strength and conditioning to ensure eccentric strength for quick deceleration and varied movement development. The review (Chapter 2) also highlighted specialised players as displaying strategies associated with higher forces (albeit landing forces), which similarly, might signal a need for these targeted strength and conditioning to improve their ability to safely control these forces.

While there is much we do not understand about how sport specialisation influences youth athletes long-term, most expert opinions, recommendations, and organisational position statements support a diverse, sampling pathway over specialisation (DiFiori et al., 2014; LaPrade et al., 2016; Lloyd et al., 2016). Broadly, this appears to be justified based on studies that have shown that elite/professional level adult athletes predominantly followed a diverse pathway (Bridge & Toms, 2013; Buckley et al., 2017). Additionally, the increased rate of injuries reported in specialised youth, justify the need for recommendations or guidance on how to minimise these injuries (Chapter

3)(McGowan et al., 2020). However, more research is needed to understand the mechanisms behind these injuries and their associations with specialisation.

There are three common volume recommendations for youth sport, linked to decreasing injury risk. The first suggests that youth should not participate in organised sport for more hours per week than their age in years (Brenner & Council On Sports Medicine and Fitness, 2016; LaPrade et al., 2016), with some suggesting a maximum of 16 hours (DiFiori et al., 2014; LaPrade et al., 2016; Valovich McLeod et al., 2011). The second recommendation is that youth athletes should not train in a single sport for more than eight months of the year (Brenner & Council On Sports Medicine and Fitness, 2016; DiFiori et al., 2014; Valovich McLeod et al., 2011). Third, youth should not exceed a 2:1 ratio of organised sport to free play (Brenner & Council On Sports Medicine and Fitness, 2016; McGowan et al., 2020). While these recommendations are widely cited in research, there is still a scarcity of evidence to support them. There is also much more nuance to these factors than these recommendations suggest. Firstly, not all training is equal. How much training is appropriate depends on the type and the quality of training, as well as the characteristics of the athlete and the coach. Secondly, the recommendation avoid training for a single sport for more than 8 months of a year is an arbitrary cut-off. No evidence exists to suggest this is better than using alternative cut-offs of, such as 7 months or 9 months. Third, just as not all training is equal, not all play is equal. The ratio of organised training to free play that is appropriate depends on the coaching quality and on the type of play, among other factors. In reality, the volume of sport participation that is appropriate for each athlete will vary based on the individual, the sport, and a myriad of external factors. More evidence is needed to determine specific guidance for specific sports, especially regarding sport specialisation.

Strengths and limitations

A strength of this thesis was the connection to industry and collaboration with NZ Football, particularly in the early stages in developing research questions that were relevant and of interest to them, in the NZ context. Accordingly, and to address the concerning high injury rates in the youth footballers (Chapter 3), there has been a high focus on neuromuscular training, including the FIFA 11+ warm up as a requirement for training sessions at all levels and ages (New Zealand Football, 2016b). The results of Chapter 4 suggest there may be some benefit from these changes made by NZ Football, with high specialised players, who likely had higher exposure, demonstrating improved jump landing strategy compared to lower specialised players. A consideration to this is the lack of structured strength and conditioning training in youth sport in NZ, which means that, outside of any coaching from their sports, these players had likely had little input into their movement development. Highly specialised players, therefore, may have benefited from greater access to educated coaches who could support their neuromuscular development.

Another strength of this thesis is the focus on a single sport, allowing a more focussed investigation of the potential differences based on specialised versus diverse pathways. Additionally, biological maturation was accounted for which is known to influence movement competency (Myer et al., 2013; Read et al., 2018b; Read et al., 2018d). This thesis also provides preliminary evidence for the impact of 'early' specialisation which for many is the topic of most interest. However, as is always the case, there were some limitations that should be acknowledged. Specific methodological limitations were discussed in detail in the relevant chapters but do need to be considered in relation to the thesis. Most of these limitations surround the sample size and cross-sectional design. While every effort was made to minimise these limitations, the findings of this thesis should be interpreted with the following limitations in mind:

- Recall bias in the reporting of injury history (Chapter 3) and in the reporting of sport participation history (Chapters 3, 4, 5, 6). This could have influenced the classification of participants as well as the analysis based on the number of years specialised. To minimise this, the limit of 12 months was put on the injury history and participants were allowed to discuss responses with parents to help with recall.
- Confounding due to previous injury (Chapters 3, 4, 5, 6). To minimise this, participants with a current injury were excluded, however, due to already having low sample sizes it was not possible to exclude all those with previous injuries.
- Chapters 3, 4, 5, and 6 all had smaller sample sizes than originally planned but due to disruptions caused by Covid-19, recruitment was made more difficult.
- The lack of longitudinal data was also not the original plan but was necessitated by delays and interruptions caused by Covid-19. Chapter 4 was originally planned as a longitudinal study across a football season.

- Chapters 4, 5, and 6 have inferred some associations with injury risk, but as they were cross-sectional and injuries were not actually recorded, these are theoretical inferences only.
- The cross-sectional design of Chapters 3, 4, 5, and 6 do not allow cause and effect to be established. I was unable to determine what came first – specialisation or movement (Chapters 4, 5, and 6)/injury (Chapter 3) characteristics.
- Participants classed as having followed a specialised pathway (Chapters 5 and 6) may have been specialised for a few years, but most had played some other sports at some point in their life which means that they had also been exposed to more varied movement patterns which may have had a confounding effect on results.
- These results are specific to NZ youth football players and may not be applicable in other countries due to differing coaching, club, and academy structures.

Practical recommendations

The findings of this thesis lead to the following practical recommendations:

- Given the high rates of injury, volume recommendations for youth sport participation may be too high, particularly during periods of rapid growth.
- Better communication and education are needed with key stakeholders (parents, coaches, and players) around the pros and cons of youth specialising in football, given the high prevalence of both specialisation and injuries.
- Strength and conditioning and plyometric skills, including jump landings and dynamic balance, at a level appropriate to maturation, age and technical competency would be beneficial for all youth football players.
- Diversified youth football players may benefit from targeted, football-specific sprint and COD training.
- Specialised youth football players may benefit from training to optimise COD technique and avoid strategies known to increase injury risk. A suggestion is for players to participate in appropriate strength and conditioning with an increased focus on eccentric leg and hip strength, unilateral strength, and plyometric training.

- Regardless of specialisation status, it is important that training of youth footballers (and other sports) be adjusted based on their abilities and needs. The high injury rates and varying movement competency shown across all specialisation levels and development pathways throughout this thesis suggest a need for targeted strength and conditioning in youth football in NZ. This may mean that there is also a need for more coach education around how best to develop and structure strength and conditioning sessions at an appropriate level for their players.

Recommendations for future research

- The focus for future research should primarily be on prospective studies to enable a better understanding of the effect of sport specialisation on movement competency in youth. Ideally, this would involve longitudinally tracking of players starting at a young age, at the same level before specialising and recording how participation, movement, and performance change over time as well as any injuries that occur.
- More sport-specific research is needed to identify changes occurring due to specialisation in specific sports, given this likely varies. This will allow more sport-specific recommendations to be made.
- Movement strategy should be assessed across a broad range of tasks, rather than solely movement output, as it appears diverse and specialised players may be able to produce similar outputs but could use differing strategies to achieve these outputs.
- Mechanisms associated with the increased incidence of gradual onset injuries should be investigated in more detail.
- More work is needed to develop consistent methods to classify specialisation to allow consistency across studies. The recent consensus definition was a good step towards this, but it was not accompanied by any resource to help with classification.

Conclusion

This thesis provides several novel perspectives on sport (and early) specialisation and movement competency in NZ youth footballers. The prevalence of specialisation was found to be high in NZ youth football and highly specialised youth players were more likely to have a history of gradual onset injury. While movement competency is a potential contributor to injury risk, variable links between movement competency and specialisation in youth football players were observed. Early specialised players (pre-PHV) exhibited improved movement competency compared to lower specialised players; however, these results were not consistent with those found in more mature (post-PHV) players. There was some evidence of improved task-specific performance outcomes in post-PHV players who had followed a specialised pathway. However, the movement strategies used to achieve these outcomes were associated with increased injury risk. Further longitudinal research is required to better understand the effect of sport specialisation on movement competency in youth football.

Participants in this research were all high-level footballers in their respective age groups. This shows that high level sport participation can be achieved by specialising but also by following a diverse development pathway. It appears that attainment of elite youth level football is not negatively influenced by playing more than one sport. There is, however, potential for negative long-term outcomes if youth focus on single sport specialisation from a young age but this requires further research to substantiate. While some level of specialisation is required to reach elite level, most youth who play at a high level will not achieve elite adult level performance. Many will develop injuries, burn out, or drop out. There is still a disconnect between the messages being portrayed by coaches and sporting organisations compared to those in the literature. This thesis provides support for the notion of reframing youth football, to support young athletes to continue long, positive participation in football.

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Appendices

Appendix A

Ethics approval (Chapter 3)

AUT

AUTEC Secretariat

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

26 April 2018

Chris Whatman
Faculty of Health and Environmental Sciences

Dear Chris

Ethics Application: **18/158 Early specialisation, training volumes and musculoskeletal injury in youth football players in New Zealand**

I wish to advise you that a subcommittee of the Auckland University of Technology Ethics Committee (AUTEC) has **approved** your ethics application.

This approval is for three years, expiring 26 April 2021.

Non-Standard Conditions of Approval

1. Customise the questionnaire to football.

Non-standard conditions must be completed before commencing your study. Non-standard conditions do not need to be submitted to or reviewed by AUTEC before commencing your study.

Standard Conditions of Approval

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

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

AUTEC grants ethical approval only. If you require management approval for access for your research from another institution or organisation then you are responsible for obtaining it. You are reminded that it is your responsibility to ensure that the spelling and grammar of documents being provided to participants or external organisations is of a high standard.

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

Yours sincerely,

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

Cc: anja.zoellner@aut.ac.nz; Denny Wells

Appendix B

Ethics approval (Chapter 4)

Auckland University of Technology Ethics Committee (AUTEC)

Auckland University of Technology
D-88, Private Bag 92006, Auckland 1142, NZ
T: +64 9 921 9999 ext. 8316
E: ethics@aut.ac.nz
www.aut.ac.nz/researchethics

15 May 2020

Chris Whatman
Faculty of Health and Environmental Sciences

Dear Chris

Re Ethics Application: **20/45 Prospective study of early specialised New Zealand Football players**

Thank you for providing evidence as requested, which satisfies the points raised by the Auckland University of Technology Ethics Committee (AUTEC).

Your ethics application has been approved for three years until 14 May 2023.

Standard Conditions of Approval

1. The research is to be undertaken in accordance with the Auckland University of Technology Code of Conduct for Research and as approved by AUTEC in this application.
2. A progress report is due annually on the anniversary of the approval date, using the EA2 form.
3. A final report is due at the expiration of the approval period, or, upon completion of project, using the EA3 form.
4. Any amendments to the project must be approved by AUTEC prior to being implemented. Amendments can be requested using the EA2 form.
5. Any serious or unexpected adverse events must be reported to AUTEC Secretariat as a matter of priority.
6. Any unforeseen events that might affect continued ethical acceptability of the project should also be reported to the AUTEC Secretariat as a matter of priority.
7. It is your responsibility to ensure that the spelling and grammar of documents being provided to participants or external organisations is of a high standard and that all the dates on the documents are updated.

AUTEC grants ethical approval only. You are responsible for obtaining management approval for access for your research from any institution or organisation at which your research is being conducted and you need to meet all ethical, legal, public health, and locality obligations or requirements for the jurisdictions in which the research is being undertaken.

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

For any enquiries please contact ethics@aut.ac.nz. The forms mentioned above are available online through http://www.aut.ac.nz/research/researchethics

(This is a computer-generated letter for which no signature is required)

The AUTEC Secretariat
Auckland University of Technology Ethics Committee

Cc: anja.zoellner@aut.ac.nz; ksheerin@aut.ac.nz

Appendix C

Ethics approval (Chapters 5 and 6)

AUT

TE WĀNANGA ARONUI O TĀMAKI MAKAU RAU

Auckland University of Technology Ethics Committee (AUTEC)

Auckland University of Technology
D-88, Private Bag 92006, Auckland 1142, NZ
T: +64 9 921 9999 ext. 8316
E: ethics@aut.ac.nz
www.aut.ac.nz/researchethics

16 May 2019

Chris Whatman
Faculty of Health and Environmental Sciences

Dear Chris

Re Ethics Application: **19/113 Early specialisation and movement competency in male youth football players: A cross-sectional study**

Thank you for providing evidence as requested, which satisfies the points raised by the Auckland University of Technology Ethics Committee (AUTEC).

Your ethics application has been approved for three years until 16 May 2022.

Standard Conditions of Approval

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

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

AUTEC grants ethical approval only. If you require management approval for access for your research from another institution or organisation, then you are responsible for obtaining it. You are reminded that it is your responsibility to ensure that the spelling and grammar of documents being provided to participants or external organisations is of a high standard.

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

Yours sincerely,

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

Cc: anja.zoellner@aut.ac.nz; ksheerin@aut.ac.nz

Appendix D

Search Strategy (Chapter 2)

Table A 1: Search strategy

Early speciali?ation	AND	Movement competenc* Movement ability Movement control Movement pattern Physical performance Coordination Fitness Motor skill Motor development Movement performance Neuromuscular control Balance Asymmetr*		
Sport Speciali?ation	AND	High school OR youth	AND	Movement competenc* Movement ability Movement control Movement pattern Physical performance Coordination Fitness Motor skill Motor development Movement performance Neuromuscular control Balance Asymmetr*
Early sport speciali?ation	AND	Movement competenc* Movement ability Movement control Movement pattern Physical performance Coordination Fitness Motor skill Motor development Movement performance Neuromuscular control Balance		

		Asymmetr*		
Single sport	AND	High school OR youth	AND	Movement competenc* Movement ability Movement control Movement pattern Physical performance Coordination Fitness Motor skill Motor development Movement performance Neuromuscular control Balance Asymmetr*

Appendix E

Interpretations of Quality Analysis Questions (Chapter 2)

Table A 2:Interpretation of quality analysis questions

Analysis item	Interpretation
Study design was clearly stated	Study design was stated either in the abstract or the methods section of the article.
Study objective/purpose is clearly stated	Study objective/purpose was outlined either in the abstract or introduction section of the article.
The study clearly states the inclusion criteria for participants	Inclusion and/or exclusion criteria was clearly outlined.
The characteristics of the population are detailed	Population characteristics including at least age, sex, and sport outlined.
The study population is representative of the intended population for which the research is aimed	Sample characteristics were clearly outlined including age, sex, and sport and matched those of the intended population. No additional exclusion criteria were applied to make the sample characteristics differ from the population of interest.
A justification for the selection of the sample/study population size is provided	Power calculation was used to inform the required sample size.
The methods used throughout testing are well detailed	Sufficient detail is provided to enable the reader to replicate the study.
The measurement tools used throughout the study are reliable and have been validated	As there is no validated measure of sport specialisation, this was applied only to the measurement of movement competency.
Detail on the statistical methods used was provided	Clear description of the statistical tests used, including significance levels.
The results of the study are well detailed	Results reported for all tests/measurements including raw data and outcomes of statistical tests.
The information provided in the paper is sufficient information was provided so to allow the reader to make unbiased assessment of the study findings	Raw data clearly reported allowing the reader to interpret these results, including information of statistical significance, variation, confidence intervals or effect sizes.
Confounding factors within the study are identified	Confounding factors were acknowledged, and some attempt was made to control for these.
Study funding/conflicts of interest were acknowledged	Funding/conflicts of interest clearly acknowledged.
Limitations to the study were identified	Main limitations of the study clearly outlined.

Appendix F

Study Quality and Risk of Bias Assessment (Chapter 2)

Table A 3: Study quality and risk of bias

Study	Barfield and Oliver (2019)	Beese et al. (2015)	DiCesare et al. (2019a)	DiCesare et al. (2019b)	DiStefano et al. (2018)	Fransen et al. (2012)	Gorman et al. (2012)	Herman et al. (2019)	Miller et al. (2017)	Peckham et al. (2018)	Root et al. (2019)	Sugimoto et al. (2019)	Triplett et al. (2018)
Study design was clearly stated	0	1	1	1	1	1	0	1	1	1	1	1	1
Study objective/ purpose is clearly stated	1	1	1	1	1	1	1	1	1	1	1	1	1
The study has a clearly testable hypothesis	1	1	1	1	1	1	0	1	1	1	1	1	1
The study clearly states the inclusion criteria for participants	0	1	1	1	0	0	1	1	1	1	1	0	0
The characteristics of the population are well detailed	0	0	1	1	1	0	0	1	0	0	1	1	0

The study population is representative of the intended population for which the research is aimed	1	0	1	1	1	0	0	0	0	0	1	0	0
A justification for the selection of the sample/study population size was provided	1	1	0	0	1	0	1	0	0	1	0	0	0
The methods used throughout testing are well detailed	1	1	1	1	1	0	1	1	1	1	0	0	0
The measurement tools used throughout the study are reliable and have been validated	1	1	1	1	1	1	1	1	1	1	1	1	1
Detail on the statistical methods used was provided	1	1	1	1	1	1	1	1	1	1	1	1	0
The statistical methods used to analyse the data were appropriate	1	1	1	1	1	1	1	1	1	1	1	1	0
The results of the study are well detailed	1	1	1	1	1	1	1	1	1	1	1	1	0

The information provided in the paper is sufficient information was provided so to allow the reader to make an unbiased assessment of the study findings	1	1	1	1	1	1	1	1	1	1	1	1	0
Confounding factors within the study are identified	0	0	1	1	1	0	0	0	0	0	1	0	0
Study funding/ conflicts of interest were acknowledged	0	0	1	1	1	1	1	1	1	1	0	1	0
Limitations to the study were identified	1	1	1	1	1	1	1	1	1	1	1	1	1
Total (/16)	11	12	15	15	15	10	11	13	12	13	13	11	5
RoB	Low	Low	Low	Low	Low	Satisfactory	Low	Low	Low	Low	Low	Low	High

Risk of bias (RoB) classified as high (0-5), satisfactory (6-10), or low (11-16).

Appendix G

Football Participation Questionnaire (Chapter 3)

FOOTBALL PARTICIPATION QUESTIONNAIRE

AUT

This questionnaire asks you to report on sports you play competitively (including football) and injuries you have sustained playing competitive sport. Please read the instructions at the start of each section carefully. You do not need to answer any questions that you do not feel comfortable answering. ***By completing this survey, you are indicating you are happy for the information you have given to be included in this research project. Data from all completed surveys will be published in a report written by a student from AUT.***

Demographic Questions

1 Are you?

- Male
- Female

2 Year and month of birth

3 What school do you go to?

4 What school year are you currently in?

5 Ethnicity

Sport participation

The following questions relate to your structured football activities.

6 Have you only ever played football?

- Yes
- No

7 Have you quit other sports to focus on football?

- Yes – if yes, at what age? ________
- No

8 Over the last 12 months have you trained more than 8 months out of the year in football?

- Yes
- No

9 Do you consider football more important than other sports?

- Yes
- No

PTO

10 During the past 12 months, what organised sport (practices and games, including football) have you participated in?

Please note the time spent, and indicate if the sport is in summer "S", winter "W" or all year "AY"
Summer = sport played in school terms 1 and/or 4
Winter = sport played in school terms 2 and/or 3

Mon	*Eg: Volleyball training 1 hour "S"*
Tues	
Wed	
Thurs	
Fri	
Sat	*Eg. Football game 1hr "W"*
Sun	

11 Outside of school hours, on average, how many hours per week are you involved in non-structured exercise/activity?

This refers to play, or sporting activity that is just for fun. ie Riding bikes, skateboarding, playing at the park, skiing for recreation, swimming at beach, surfing, playing on playgrounds

Hours/week

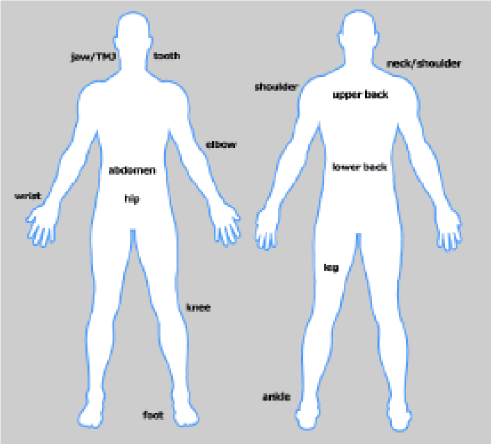
Injury history

The following section asks about injuries that you have sustained when playing or training for competitive sport (including football) over the **past 12 months.**

12 Have you suffered from an injury that caused you to miss at least one day of sport participation?

- Yes → Go to **13**
- No → Go to **14**

13 Please circle the area/s the injury occurred on the chart below, and take it to the researcher to discuss what type of injury it was.



14 Have you sustained any injuries while playing or practicing sport that you have continued to play through?

- Yes → Mark on chart in Q **13**
- No → Thank-you for completing the survey.

15 Have you ever sustained an Anterior Cruciate Ligament (ACL) injury?

- Yes → How old were you when this occurred?
- No

For research assistant use only

SITE	ACUTE Contact	ACUTE non-contact	GRADUAL ONSET	Did this occur during football?
1				
2				
3				
4				
5				
6				

Appendix H

Football Participation History Survey (Chapters 4, 5, 6)

AUT

FOOTBALL PARTICIPATION HISTORY

This questionnaire asks you to report on your history of football participation, and which other sports you have played during this time. Please read the questions carefully. You do not need to answer any questions that you do not feel comfortable answering.

Name: ________________________ Participant ID: ________________________

1. Age:

2. What school do you go to?

3. Which ethnic group do you belong to?
   Circle the option/s which apply to you.

NZ European   Maori   Samoan   Chinese   Cook Island Maori   Tongan   Indian   English

Australian   Fijian   Korean   Other (please state): ________________

<u>Football history questions:</u>

4. Do you play football for school?
   a. Yes

   b. No

5. At what age did you start playing football?

6. Do you consider football more important than any other sport?
   a. Yes

   b. No

7. Do you train more than 8 months out of the year in football?
   a. Yes   - At what age did you start training more than 8 months of the year in football? ______

   b. No

8. Have you quit other sports to focus on football?
   a. Yes   - At what age?

   b. No

9. Have you only ever played football and no other organised sports? If Yes please go to question 10.
   a. Yes

   b. No

Please circle which sports you played at each age from 5 to 18 (circle as many as needed).

5. Football, Futsal, Tennis, Basketball, Cricket, Hockey, Swimming, Water Polo, Rugby, Touch, Other:________________
6. Football, Futsal, Tennis, Basketball, Cricket, Hockey, Swimming, Water Polo, Rugby, Touch, Other:________________
7. Football, Futsal, Tennis, Basketball, Cricket, Hockey, Swimming, Water Polo, Rugby, Touch, Other:________________
8. Football, Futsal, Tennis, Basketball, Cricket, Hockey, Swimming, Water Polo, Rugby, Touch, Other:________________
9. Football, Futsal, Tennis, Basketball, Cricket, Hockey, Swimming, Water Polo, Rugby, Touch, Other:________________
10. Football, Futsal, Tennis, Basketball, Cricket, Hockey, Swimming, Water Polo, Rugby, Touch, Other:________________
11. Football, Futsal, Tennis, Basketball, Cricket, Hockey, Swimming, Water Polo, Rugby, Touch, Other:________________
12. Football, Futsal, Tennis, Basketball, Cricket, Hockey, Swimming, Water Polo, Rugby, Touch, Other:________________
13. Football, Futsal, Tennis, Basketball, Cricket, Hockey, Swimming, Water Polo, Rugby, Touch, Other:________________
14. Football, Futsal, Tennis, Basketball, Cricket, Hockey, Swimming, Water Polo, Rugby, Touch, Other:________________
15. Football, Futsal, Tennis, Basketball, Cricket, Hockey, Swimming, Water Polo, Rugby, Touch, Other:________________
16. Football, Futsal, Tennis, Basketball, Cricket, Hockey, Swimming, Water Polo, Rugby, Touch, Other:________________
17. Football, Futsal, Tennis, Basketball, Cricket, Hockey, Swimming, Water Polo, Rugby, Touch, Other:________________
18. Football, Futsal, Tennis, Basketball, Cricket, Hockey, Swimming, Water Polo, Rugby, Touch, Other:________________

10. Please list any injuries (in any sport) you have had in the last 12 months that have caused you to miss games or trainings. Provide information about what sport and how the injury happened.

    Eg: Sprained right ankle in football game, tripped on ball and twisted foot.