Sports Specialisation, Balance Performance and Injury in a group of New Zealand Adolescents

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Attestation of Authorship

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

Chapters 3 and 4 of this thesis represent two separate papers that have been submitted to peer-reviewed journals for consideration for publication. My contribution and the contribution by the various co-authors to each of these papers are outlined at the beginning of this thesis. All co-authors have approved the inclusion of the joint work in this Master's thesis.

Rhys Norton

May 2021

Candidate Contribution of Co-authored Papers

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	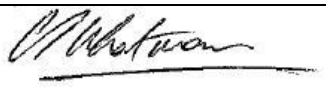		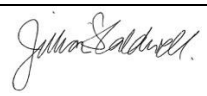
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Ethical Approval

Ethical approval for this research was granted by the Auckland University of Technology Ethics Committee (AUTEC). The AUTEC reference was 19/122, with approval granted originally on the 7th of June 2019 and an amendment approved on the 14th of July 2020.

Abstract

With youth sport becoming increasingly professionalised and competitive, there has been a trend towards more frequent, structured and high-intensity sport from an early age. Although injuries in adolescents are multi-factorial, sport specialisation and high sport participation volume during adolescence has been linked to increased risk of sustaining injuries, particularly overuse type injuries. Injury risk may be higher during adolescence due to the anatomical changes that occur during the period of peak skeletal growth as well as general decreases in coordination and motor control. Research in this area has grown recently highlighting the need for further evidence to help develop the most appropriate guidelines for adolescent engagement in sport. Therefore, the primary aim of this thesis was to examine the association between specialisation level and injury history, in both the high school sport setting and in the environment of a performance-based sporting academy. A secondary aim of this thesis was to examine the association between specialisation and neuromuscular performance, specifically performance on the Y-balance test.

In the first study of the thesis a questionnaire survey was used to gather information from 199 secondary school students aged 12-16-years-old regarding their sporting participation and injury history over the past 12 months. After adjusting for relevant confounding variables (including gender, school year, exceeding a 2:1 ratio of weekly organised sport hours to weekly recreational free-play hours and hours of weekly sport volume), there was no significant association between specialisation level and reporting an injury. However, there was a significant association between reporting a time-loss injury and weekly hours of sport volume (p=0.011). For every hour of additional sport volume, participants were 1.13 (95% CI: 1.03-1.24) times more likely to report a time-loss injury. Furthermore, although there was no statistically significant association between specialisation level and being involved in a high-performance academy, participants from the academy were 6.8 times more likely to exceed the recommended 2:1 ratio of weekly organised sport hours relative to free-play hours (p=0.001). Sport volume was also significantly higher (p=0.006) in the sports academy group (median 8.0 hours) compared to the school group (median 4.5 hours).

In the second study of the thesis, the Y-balance test was used to evaluate balance performance as a measure of neuromuscular control. It has been suggested that sport specialisation may inhibit neuromuscular development due to the reduced range of movement challenges. However, this study did not find an association between specialisation level and Y-balance test performance. Additionally, the second study highlighted that injuries often considered to be growth-related were common in this population of adolescents, with the most common diagnoses being patella-femoral pain and

tendinopathy/enthesopathy type injuries to the lower limb, such as Sever's disease and Osgood-Schlatter's disease.

In conclusion, in this group of NZ adolescents, sport specialisation did not increase the likelihood of reporting a history of injury nor did it result in worse balance performance. However, increased weekly sport volume did increase the likelihood of reporting a time-loss injury. Furthermore, involvement in a performance-based sport academy did not increase single sport specialisation but it did increase sport volumes and decreased recreational free-play. Therefore, monitoring sport volumes may help to decrease injuries in this age group, and this may be even more important in the sports academy setting in New Zealand.

Chapter 1: Introduction

1.1 Background

The benefits of sport participation during adolescence are widely acknowledged, including improved quality of life, self-image and social relationships (Hecimovich, 2004). Adolescent sport participation has been shown to have ongoing health benefits into later life, with active adolescents shown to be much more likely to become active adults and show a marked decrease in morbidity and mortality (Brenner, 2007; Hecimovich, 2004, Menschik et al., 2008; Troutman & Dufur, 2007). Furthermore, sport participation in adolescents has been shown to decrease rates of smoking and improve attendance and academic performance in school (Hecimovich, 2004). However, there is also an inherent risk of musculoskeletal injury that comes with sport participation which comes at a significant cost. Data from New Zealand's no fault national insurer the Accident Compensation Corporation (ACC) shows that acute injuries in the 10-19 years age group cost of over $100 million in 2017 (Accident Compensation Corporation, n.d.)

Many injuries occur in both the individual and team sport environments, through contact and non-contact situations. It is evident that acute and overuse injuries are a significant issue in active adolescents, with eight percent of adolescents dropping out of sport due to injury or fear of injury (Myer et al., 2015). Therefore, clear evidence-based guidelines around sport participation for adolescents are needed to reduce the risk of these overuse injuries. A reduction in injury risk should result in decreased drop out from sport, giving adolescents the chance to be participating over a longer time frame and providing a more positive sport experience. This may maximise the mental, physical and social health benefits of sport participation and increase the chances of adolescents becoming more active, healthier adults.

1.2 Statement of the Issues

1.2.1 Injuries are increasing in adolescent sport

Overseas research suggests that the prevalence of sport-related injuries in adolescents has increased over the past 20 years. One Australian study showing a 61% increase between 2003 and 2012 (Shee et al., 2017) and a Canadian study indicating a 28% increase between 1992 and 2005 (Pakzad-Vaezi & Singhal, 2011). In New Zealand, the Accident Compensation Corporation (ACC) statistics have shown

a 60% increase in sport-related injuries in the 10-14 age group in the last 10 years (Wilson, 2019). ACC is a government-funded organisation that funds assessment, treatment and earnings related compensation to anyone in New Zealand that sustains an injury as a result of an accident. ACC define an accident as a specific incident, event or series of events which cause an injury to a person and they define physical injury as resulting in actual damage to the body (Accident Compensation Corporation, n.d.). Due to the definitions and guidelines used to determine covered injuries, ACC statistics most likely account for acute injuries that are assessed and diagnosed by a registered health professional and are less likely to capture all gradual onset or overuse injuries. This may result in an under-reporting of overuse injuries in New Zealand.

Acute injuries are often defined as being related to a single, traumatic event while overuse injuries are defined as gradual onset without a specific sports-related event (Jayanthi et al., 2015; Jayanthi et al., 2018; Moseid et al., 2019; Pasulka et al., 2017). Research has estimated that the incidence of overuse injuries is approximately 50% of all sport-related injuries (DiFiori et al., 2014). In New Zealand, a recent study of 914 adolescents aged 10-13 years reported a total of 1,536 sport-related injuries occurring over the previous year, of which 78% were considered acute and 22% gradual onset (McGowan et al., 2020). Injury risk may be higher during adolescence due to the anatomical changes that occur during the period of peak skeletal growth (Sanders et al., 2017). During this period, epiphyseal growth plates in the long bones undergo rapid proliferation and growth and are particularly susceptible to overuse injury (Hosseinzadeh & Milbrandt, 2011). In addition, there is often an imbalance between the length of the limbs and the strength of the surrounding musculature, as well as a general decrease in coordination and motor control (Beese et al., 2015). Common overuse related injuries reported in adolescents include patellofemoral pain (PFP), patellar tendinopathy, Osgood-Schlatter disease and Sever's disease (McKay et al., 2016).

1.2.2 Changes in adolescent sport participation

Adolescent sport participation has changed over the last decade, both in New Zealand and internationally (Bergeron, 2010; Sam & Ronglan, 2007). Youth sport is becoming increasingly professionalised and competitive, with talent identification occurring at younger ages and a larger emphasis on performance pathways towards elite sport (Bergeron, 2010). As a result, there has been a trend towards more frequent, structured and high intensity sport from an earlier age (Buckley et al., 2017). This increased competitiveness is often accompanied by increased volume and frequency of competition with insufficient time for rest and recovery (Bergeron, 2010).

The combination of early talent identification, highly competitive sport pathways and motivation to attain elite status, professional contracts or scholarships has led to an increase in sport specialisation at younger ages (Bergeron, 2010; Buckley et al., 2017). Sport specialisation has been commonly defined as year-round intensive training in a single sport at the exclusion of other sports (Jayanthi et al., 2015). One catalyst that is thought to have contributed to the early sport specialisation model is a study by Ericsson and colleagues in 1993 which developed what is known as the '10,000 hour rule'. Although this study was conducted with musicians, some of the findings have since been applied in the sporting environment. The authors investigated adult violinists and found that those that began training at an early age were more likely to develop expert level skills than those that picked it up later in life. They proposed that time spent in practice was the critical determinant of level of performance, with approximately 10,000 hours of deliberate practice accumulated over time needed to become an expert (Ericsson et al., 1993). Deliberate practice was classified as not play, not paid work, not watching the skill being performed, not inherently enjoyable, requiring effort and attention from the learner and often involving activities selected by a coach or teacher to facilitate learning. The study had limitations, including the authors not reporting on the variation in total practice hours, with some violinists attaining expert level skills in much less than the reported 10,000 hours. Despite this and the fact that this research involved violinists, this 'rule' has since been applied to the sporting environment, whereby sport has been driven by this belief that the more deliberate sport-specific practice is accumulated over time, the more likely the athlete is to attain expertise and excel at a high level (Helsen et al., 1998). Not with standing that the evidence from the study doesn't actually support the 'rule', one may argue that there is a potential disconnect between skill acquisition in music versus sport and that the results of the research may not be applicable to the sporting environment.

There appears to be many reasons that an athlete might choose to specialise in one sport. Sport specialisation from a young age is a recognised development pathway that can lead to some athletes achieving elite sporting success such as Serena and Venus Williams and Tiger Woods (Bailey, 2015; Smith, 2015). The specialisation story of these hugely successful elite athletes may have led to some coaches, parents and young athletes believing that sport specialisation is essential for future sport success and that a high level of youth sport success predicts future sporting success (DiFiori et al., 2017). The decision to specialise often occurs with the hopes of increasing chances of gaining university scholarships or professional contracts (Buckley et al., 2017). Moreover, parents and athletes can be concerned that not specialising at a young age could place children at a significant disadvantage to their peers (DiFiori et al., 2017). These beliefs may be warranted in certain sports that suit the early specialisation pathway; one of which being gymnastics, where high level performance is easier to

attain when athletes are physically smaller. Therefore, athletes will typically reach peak performance at a young age but will likely have a relatively short career. However, recent evidence suggests that youth success has very little correlation with long-term success in most sports and in some cases may be detrimental to long term sport participation (Brenner et al, 2016; Buckley et al., 2017). Sport specialisation and high sport participation volume during adolescence has also been linked to increased risk of sustaining injuries, particularly overuse type injuries (Brenner et al., 2016; Hall et al., 2015; Jayanthi et al., 2015; McGuine et al., 2017; Post et al., 2017). Other proposed negatives of sport specialisation in adolescence include psychosocial issues such as burnout, social isolation and high rates of drop-out (Brenner et al, 2016; Buckley et al., 2017).

The alternative to sport specialisation is known as sport sampling. Sport sampling involves participating in a variety of sports throughout childhood and adolescence and is also characterised by utilising deliberate play rather than deliberate practice (Coté et al., 2009). Deliberate play has been defined as activities in which children participate solely because they enjoy them, (Côté & Jennifer, 2012). Sport sampling in adolescence is thought to provide some protection from injury, possibly by means of reduced sporting intensity and volume, or by exposing adolescents to a greater variety of movement patterns and allowing for increased neuromuscular development. Limiting the variety of movement patterns via specialising in one sport is thought to cause possible underdevelopment of key areas of neuromuscular development including endurance, stability, movement quality, power, agility, strength, flexibility and speed (Distefano et al., 2018). The sport sampling pathway is thought to have two likely outcomes once the athlete has matured, with some athletes continuing to participate in recreational sport and others ending up performing at an elite level (Côté & Jennifer, 2012). Contrary to the 10,000 hour/early specialisation model, research has identified several examples of athletes reaching elite status after following the pathway of sport sampling in adolescence and specialising later in life (Buckley et al., 2017). In comparison, the early specialisation model may result in elite performance, however there are also higher rates of dropout (Côté & Jennifer, 2012). The comparison between the sport specialisation and sport sampling pathways has been summarised in the figure by Côté & Jennifer (2012) which shows the different pathways an athlete can take to reach recreational participation or elite performance (See Figure 1).

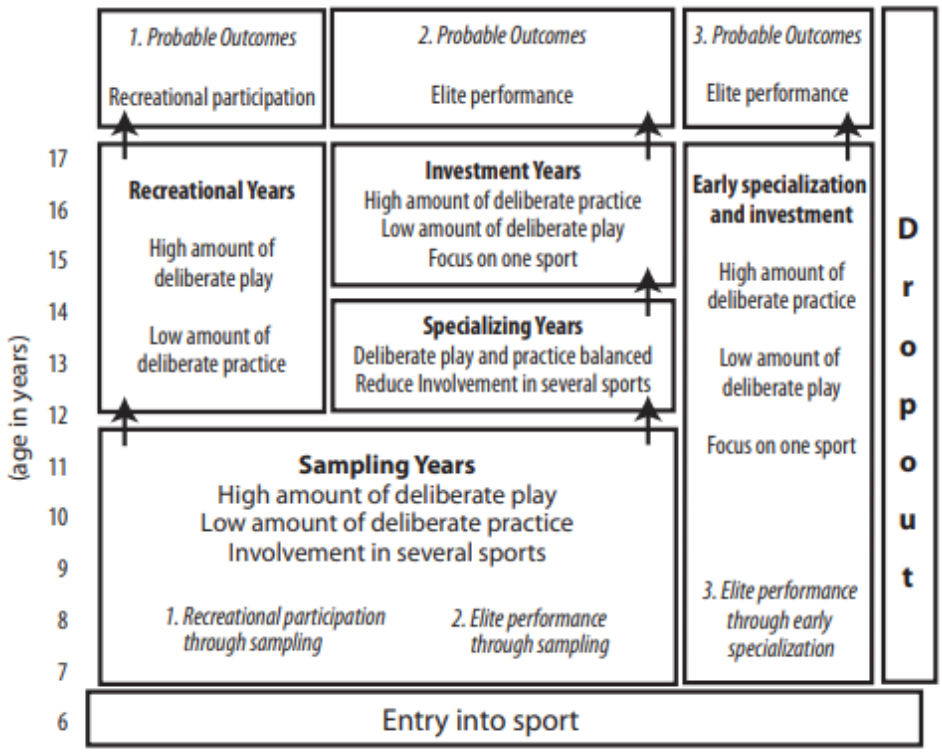

Figure 1: The Development Model of Sport Specialisation adapted from (Côté & Jennifer, 2012).

Current published guidelines from the American Academy of Pediatrics and the American Medical Society for Sports Medicine state that specialisation in a single sport should be avoided until late adolescence due to the increased risk of developing an overuse injury (DiFiori et al., 2014; Fabricant et al., 2016; Jayanthi et al., 2013; LaPrade et al., 2016; McLeod et al., 2011; Myer et al., 2015). However, the authors acknowledge that this recommendation is mostly based on expert opinion, as there is limited research to support these recommendations (DiFiori et al., 2014). The National Basketball Association (NBA) and USA Basketball have discouraged specialisation before the age of 16, stating that youth should be given the opportunity and encouraged to participate in a diverse range of activities (DiFiori et al., 2018). Similar recommendations have been provided by the International Olympic Committee, encouraging children to participate in a variety of different, unstructured and structured sport-related activities (Bergeron et al., 2015). Currently there are few studies that have investigated the level of sport specialisation at the secondary school level in NZ and its relationship with injury. Similarly, there are few studies that have examined the association between early sport specialisation and areas of neuromuscular performance. As neuromuscular control is a multi-factorial concept, it can be difficult to find a valid and reliable outcome measure that captures all aspects. One of the more popular measures used in previous research has been the Y-balance test. This test

objectively captures balance performance is several directions and also symmetry of performance between limbs. While it has obvious limitations, the movements involved in the Y-balance test also capture several other components of neuromuscular performance including proprioception, joint range of motion and strength.

1.3 Aim and Research Questions

1.3.1 Aim

To investigate adolescent sport specialisation in NZ and its association with injury and neuromuscular development.

1.3.2 Research Questions

1. What is the prevalence of sport specialisation in a group of NZ adolescents?
2. Is sport specialisation associated with a history of injury in adolescents?
3. Is sport specialisation associated with balance performance?

1.4 Thesis Structure

The thesis is presented in a pathway two format and consists of five chapters. In accordance with the Auckland University of Technology's pathway two format, the thesis contains two chapters (three and four) developed for journal publication. The manuscripts in these chapters are presented as they have been submitted to, or formatted for, the target journals, and as such the repetition of some information occurs. Each chapter begins with a prelude, which serves to demonstrate the link between chapters and brings together the thesis as a cohesive whole.

Chapter 1 includes the introduction and rationale for the thesis. Chapter 2 reviews the literature around specialisation and its association with injuries and physical capability. Chapter 3 is a retrospective, cross-sectional study investigating the prevalence of specialisation in a group of adolescents in secondary school. Information was gathered about the prevalence of specialisation level of the participant and injury history of the participants. Chapter 4 is a cross-sectional study examining the association between specialisation level and balance performance in adolescents.

The Y-balance test was performed to examine the balance performance in three directions, as well as asymmetry between performance on the left and right limbs. Based on injury history as diagnosed by a physiotherapist, this study also examined the association between injury history and specialisation level. Chapter 5 is an overall discussion of key findings of the thesis, areas for further research, clinical implications and concluding statements. All references are provided at the end of the document.

Prelude to Chapter 2

In order to optimise sport participation guidelines and injury prevention strategies for adolescents, there must first be a clear understanding of sport specialisation and how this may affect various aspects of neuromuscular control and injury risk. A narrative review was conducted to add to the existing body of knowledge around sport specialisation, injury and physical capability.

Chapter 2: Sport Specialisation and its association with physical capability and injury in adolescents: A Narrative Review of the literature

2.1 Abstract

Objective: The purpose of this narrative review was to examine the literature investigating adolescent sport specialisation in relation to injury and various components of physical capability.

Background: Injuries in the active adolescent population have increased significantly over the past decade. This has been, in part, attributed to an increase in sport specialisation. It is thought that participation in a single sport for the majority of the year may expose athletes to more repetitive forces which may place them at a higher risk of developing an acute or overuse injury. At the time of this review there has been limited research done in the area of sport specialisation and its association with injury or elements of physical capability such as balance ability, landing performance, strength and joint range of motion.

Methods: A literature search was conducted in May 2019 using the electronic databases; Web of Science, Medline, CINAHL Complete and Sport Discus via EBSCO Health. Search terms that were used included injur* OR overuse OR pain*, youth OR young OR adolescen* OR immatur* OR pediatric OR paediatric OR colleg* OR "high school", sport OR athlet* OR activ*, specialis* OR specializ*, balanc* OR "star excursion" OR SEBT OR "Y balance" OR "unipedal dynamic balance" OR UPDB OR performance OR "physical ability". A total of 18 studies were included in this narrative review.

Discussion: Of the 14 studies included that focused on specialisation and injury, 10 found a significant association. Eight studies found an association between specialisation and overuse injuries. However, there is disparity in the strength of the associations found, which were affected by several methodological limitations, as well as the variation in definitions of specialisation and injury used in the studies. Of the five studies that examined the effect of specialisation on physical capability, three found an association between specialisation and a decrease in performance in their chosen outcome measure.

Conclusion: There is some evidence of a positive association between sport specialisation and increased injury history in adolescent athletes. Furthermore, there is some evidence of an association between specialisation and a decrease in physical capability, including differences in balance ability, landing performance, strength and joint range of motion.

Key words: specialisation, injury, adolescents, athletes, sport, physical capability, balance.

2.2 Introduction

It is well recognised that sport participation during adolescence has many benefits including improved quality of life, self-image and social relationships. Adolescent sport participants have been shown to be less likely to smoke and more likely to have better attendance and grades in school (Hecimovich, 2004). There is evidence that active adolescents are much more likely to remain active into their adult years and exhibit a general decrease in morbidity and mortality, including improvements in bone mineral density, lipid profile, cardiovascular endurance, muscle strength and blood pressure (Brenner, 2007; Hecimovich, 2004, Menschik et al., 2008; Troutman & Dufur, 2007). However, involvement in sport also poses a risk of musculoskeletal injury and it is evident from the literature that acute and overuse injuries are a significant issue in active adolescents. Twenty percent of adult elite athletes reported injury as a reason for retiring from their sport, and up to eight percent of adolescents drop out of sport due to injury or fear of injury (Myer et al., 2015). Importantly, the incidence of injury in adolescents appears to be increasing. An Australian study involving 5,671 children under 15 showed a 61% increase in sport-related injuries between 2003 and 2012 (Shee et al., 2017) and a Canadian study involving 27,466 sport-related injuries indicated a 28% increase between 1992 and 2005 (Pakzad-Vaezi & Singhal, 2011). In New Zealand, ACC data showed a 60 percent increase in sports-related injuries in the 10-14 age-group over the past decade (Wilson, 2019). This increase has been partly attributed to an increase in sport specialisation typically seen in adolescents.

Specialisation has been commonly defined as year-round intensive training in a single sport at the exclusion of other sports (Jayanthi et al., 2015). The current trend toward earlier sports specialisation and year-round training has raised concerns that these factors may be increasing the risk for injury. The potential link between sport specialisation and injury has been supported by the American Academy of Pediatrics, stating that adolescents that specialise may be denied the benefits of varied activity while facing additional physical, physiological, and psychological demands from intense training and competition (Pediatrics, 2000). Varied activity and movement patterns have been thought to allow for optimal development of neuromuscular control, which is defined as the afferent sensory recognition of joint position and motion and the following efferent response to that awareness (Lee et al., 2019). Neuromuscular control has a multitude of different components, including sensory factors such as proprioception as well as motor factors such as stability, movement quality, strength, flexibility and balance. Having good neuromuscular control may have a protective effect for

adolescents in sport and underdevelopment of one or more of the components of neuromuscular control may increase risk of injury (DiStefano et al., 2018). When compromised neuromuscular control is combined with increased exposure to repetitive forces, which may arise from specialising in one sport, this may place adolescents that specialise at a greater risk of overuse injury (Buckley et al., 2017). For these reasons, the American Academy of Pediatrics and the American Medical Society for Sports Medicine have both discouraged sport specialisation before adolescence. However, they acknowledge that this recommendation is mostly based on expert opinion, as there is limited research to support these recommendations (DiFiori et al., 2014).

At the time in their lives when adolescents are developing and growing the most rapidly, it is important to have well informed guidelines around sport participation. Understanding the impact of sport specialisation on neuromuscular control and injury risk will help to optimise prevention strategies through improved sport participation guidelines for the adolescent population. Therefore, the purpose of this narrative review was to examine the literature surrounding sport specialisation in adolescents and its relation to injury and various components of physical capability.

2.3 Literature Search

2.3.1 Methods

Due to the diverse range of methodologies used in the included studies, the authors believed that a narrative review structure was more suitable for the proposed research questions: Is sport specialisation associated with a history of lower limb overuse injuries in adolescents? Is sport specialisation associated with balance performance? A systematic review needs a narrow focus, whereas a narrative review can allow for a more comprehensive coverage of a more diverse range of literature, especially when the research question is less specific or the research is methodologically diverse (Collins & Fauser, 2005; Pai et al., 2004). The current narrative review will draw on the strengths of a systematic review by using a systematic approach to gather the relevant studies.

A literature search was conducted in May 2019 using the electronic databases; Web of Science, Medline, CINAHL Complete and Sport Discus via EBSCO Health. Search terms that were used included injur* OR overuse OR pain*, youth OR young OR adolescen* OR immatur* OR pediatric OR paediatric OR colleg* OR “high school”, sport OR athlet* OR activ*, specialis* OR specializ*, balanc* OR “star excursion” OR SEBT OR “Y balance” OR “unipedal dynamic balance” OR UPDB OR performance OR “physical ability”. The search was limited to the English language and duplicates were removed. A total

of 1,393 articles were identified from this search. To be included in the review, the studies had to be original published research with a focus on sport specialisation in adolescents and its association with either musculoskeletal injury or a component of physical capability. The term adolescents includes participants 19 years of age or younger (World Health Organisation, 2013). Studies were included if they were peer reviewed and published in English. Studies were excluded if they were review articles, commentaries or opinion studies. Abstracts were screened and using the inclusion criteria, 13 studies were selected for this review. A further five studies were identified from reference lists of other included studies. Therefore, a total of 18 studies were included.

2.3.2 Results

Of the 18 studies, 14 focused on the association between specialisation and injury. Of these, three were retrospective cohort studies, three were prospective cohort studies, five were cross-sectional studies and three were case-control studies. A summary of the key characteristics of the included studies is presented in Table 1. These studies were published between 2010 and 2019, with eight of them published since 2017. This suggests that research examining the association between sport specialisation and injury in adolescents is a new concept. There were 14,743 total participants across the 14 studies. The range was between 236 participants to 3,276. The mean age of the participants across all studies was 13.5 years (based on the 11 studies that reported mean ages) with an age range between 7-21. Of the 14 studies, 10 found a significant association between specialisation and injury, with eight studies reporting a specific association between specialisation and overuse injuries (Bell et al., 2016; Buckley et al., 2017; Hall et al., 2015; Jayanthi et al., 2011; Jayanthi et al., 2015; Jayanthi et al., 2018; McGuine et al., 2017; Pasulka et al., 2017; Post et al., 2017; Post et al., 2017).

Five of the studies focused on the association between specialisation and physical characteristics or physical capability, including balance, landing performance, joint range of motion and muscular strength (Beese et al., 2015; DiStefano et al., 2018; Gorman et al., 2012; Miller et al., 2017; Sugimoto et al., 2019). Four of these studies were cross-sectional studies and one was a case-control study. A summary of the key findings including research methodologies, information about the participants used and study outcomes is presented in Table 2. The studies included were published in 2012 and 2019, suggesting that although there is limited research performed in this area, it may be becoming more popular. Two studies used the Landing Error Scoring System to examine lower limb control on landing (Beese et al., 2015; DiStefano et al., 2018) and two studies used components of the Y-balance test to examine balance performance (Gorman et al., 2012; Miller et al., 2017). The fifth study used

measures of joint range of motion, muscular strength and performance measures of vertical jump and front plank (Sugimoto et al., 2019). There were 1,110 total participants across the five studies. The range was 355 participants to 40. The mean age of the participants across all studies was 14.4 years (based on the four studies that reported mean ages) with an age range of 8-18. Three of the studies found an association between specialisation and a decrease in performance in their chosen outcome measure (DiStefano et al., 2018; Miller et al., 2017, Sugimoto et al., 2019).

In order to highlight differences in the quality of evidence produced, the discussion of included studies will be separated based on study design. Prospective data will be discussed first due to the high quality of evidence this type of research provides. Subsequently, retrospective data will be discussed, including case control studies, cohort studies and cross-sectional studies.

Table 1 – Association between specialisation and injury

Study	Study design	Participants	Sport	Classification method	Injury definition	Main study outcome
Cuff et al., 2010	Retrospective cohort study	*N* = 3276 (46% female) American high school athletes Median age 16 years (range 14-19)	Any	Single sport or multisport *n* = 1271 students played same sport all year (37.3%)	Time Loss Medical Assessment *n* = 1685 total injuries *n* = 949 (56.3%) acute injuries *n* = 584 (34.7%) overuse injuries *n* = 152 (9.0%) unknown classification of injury	No significant association between reported injuries and specialisation. However, playing sports all year long without taking a break showed an increased risk of reporting an overuse injury (OR= 1.42) compared to those that played for fewer than four seasons Adjusted for exposure: No
Jayanthi et al., 2011	Retrospective Cohort study Prospective cohort study	*N* = 519 (53% female) Elite junior tennis players Mean age 13.5 years (range 10-18)	Tennis only	Single sport or multisport 69.6% reported playing and competing in only tennis	Retrospective data: Medical Assessment Prospective data: Time Loss 31.4% of players reported a prior injury related to tennis in the past year *n* = 29 medical withdrawals recorded over the four-week study period	Significant relationship (OR: 1.55, $p < 0.05$) between players who were specialised in tennis and those who reported a history of a tennis related injury or illness in the past year No significant association between specialisation and future medical withdrawal risk Adjusted for exposure: Yes

Study	Study design	Participants	Sport	Classification method	Injury definition	Main study outcome
Hall et al., 2015	Retrospective cohort study	*N* = 546 (100% female) American high school athletes Mean age 14.5 years for specialised group and 13.8 years for multi-sport group	Basketball Soccer Volleyball	Single sport or multisport *n* = 189 single sport specialised athletes	Medical Records *n* =153 (28%) had anterior knee pain at examination	Single sport specialised athletes reported a 1.5-fold greater incidence of PFP (95% CI 1.0-2.2, p=0.038) and a 4-fold greater risk of developing an overuse apophysitis (95% CI 1.5-10.1, p=0.005) compared to multi-sport athletes Adjusted for exposure: Yes
Jayanthi et al., 2015	Case-control study	*N* = 1190 (49.3% female) American athletes attending medical clinics Mean age 13.7 ± 2.3 (range 7-18)	Any	Three-point scale High = 28.1% Moderate = 33.7% Low = 38.2%	Medical Records *n* = 822 athletes reported an injury *n* = 276 (32.6%) acute injuries *n* = 570 (67.4%) overuse injuries	There was an increased odds of reporting a history of injury (OR: 1.27, $p < 0.01$) or a serious overuse injury (OR: 1.36, $p < 0.01$) among young athletes who were specialised in one sport Adjusted for exposure: Yes
Bell et al., 2016	Cross-sectional study	*N* = 302 (59.6% female) American high school athletes Mean age 15.6 years (range 13-18)	Soccer Basketball Tennis Volleyball (female only)	Single sport or multisport Three-point scale Three-point classification: High = 36.4% Moderate = 28.8% Low = 34.8% Self-classification: Multi-sport = 70.5% Single-sport = 29.5%	Specific injury outcome scale *n* = 64 (21.2%) history of knee injury *n* = 33 (10.9%) history of hip injury *n* = 33 (10.9%) history of overuse knee injury	Athletes that reported an overuse knee injury were significantly more likely (OR not specified, $p = 0.048$) to be considered highly specialised that to be in the low specialisation group Adjusted for exposure: No

Study	Study design	Participants	Sport	Classification method	Injury definition	Main study outcome
Kahlenberg et al., 2016	Cross-sectional study	*N* = 484 (41.9% female) American high school athletes Mean age 15.9 years (range 13-21)	Any	Single sport or multisport *n* = 237 (49%) reported the age they dropped all other sports to focus on their primary sport, and therefore were considered specialised	Medical Attention Time Loss 80.8% reported sustaining an injury	Single sport specialisation was not significantly associated with a higher reported injury history (OR not specified, $p = 0.608$) Adjusted for exposure: Yes
Buckley et al., 2017	Cross-sectional study	*N* = 503 (46.7% female) American high school athletes Mean age 15.3 ± 1.4 years (range not specified)	Any	Single sport or multisport 45.2% Single sport specialised	Medical Assessment Time Loss 39% reported an injury that they attributed to specialising in one sport	Current high school athletes recalled a significantly higher incidence of sustaining an injury that they attributed to specialising in one sport when compared to current collegiate and current professional athletes (OR 1.54, $p < 0.001$) Adjusted for exposure: No
Pasulka et al., 2017	Case-control study	*N* = 1190 (50.3% female) American athletes attending sports medicine clinics Mean age 13.7 ± 2.3 years (range 7-18)	Any	Single sport or multisport 26% single sport specialised	Medical Records *n* = 242 injuries in single sport specialised group (73% overuse or serious overuse)	Single sport specialised athletes in individual sports had significantly higher odds of reporting an overuse injury (OR: 1.67, $p = 0.037$) or serious overuse injury (OR: 2.38, $p = 0.011$) but significantly lower odds (OR: 0.37, $p = 0.001$) of reporting an acute injury than the single sport specialised athletes involved in team sports Adjusted for exposure: Yes

Study	Study design	Participants	Sport	Classification method	Injury definition	Main study outcome
Post et al., 2017	Cross-sectional study	*N* = 1544 (50.5% female) American high school athletes Mean age 16.1 ± 1.1 years	Any	Three-point scale High = 13.4% Moderate = 27.1% Low = 59.5%	Medical Assessment *N* = 487 (31.5%) reported a previous lower extremity injury	High level of specialisation was associated with significantly higher odds (OR: 2.58, p = 0.001) of reporting a history of a previous lower extremity injury, after adjusting for gender Adjusted for exposure: No
Post et al., 2017	Case-control study	*N* = 2011 (49% female) American athletes Mean age 13.7 ± 1.6 years (range 12-18)	Any	Three-point scale High = 37.5% Moderate = 37.3% Low = 25.2%	Time Loss *n* = 992 history of injury *n* = 377 history of overuse injury	Athletes who were highly specialised were significantly more likely to report a history of injury of any kind (OR: 1.58, p < 0.001) or a history of overuse injury (OR: 1.45, p = 0.01) in the previous year, when compared to athletes in the low specialisation group Adjusted for exposure: Yes
McGuine et al., 2017	Prospective cohort study	*N* = 1544 (50.5% female) American high school athletes Mean age 16.1 ± 1.1 years	Any	Three-point scale High = 13.3% Moderate = 27.2% Low = 59.5%	Medical Assessment *n* = 276 lower extremity injuries recorded over the school year (23.2% gradual onset injuries, 10.5% recurrent injuries)	Athletes were significantly more likely to sustain a lower extremity injury if they were moderately (HR: 1.51, p = 0.03) or highly (HR: 1.85, p = 0.02) specialised compared with athletes in the low specialisation group Athletes in the high specialisation group were significantly more likely to sustain a chronic lower extremity injury (HR: 4.74, p < 0.001) than athletes in the low specialisation group. Adjusted for exposure: No

Study	Study design	Participants	Sport	Classification method	Injury definition	Main study outcome
Jayanthi et al., 2018	Retrospective cohort study	*N* = 1139 (48.6% female) American athletes attending sports medicine clinic Mean age 13.70 ± 2.3 years (range 7-18)	Any	Three-point scale High: 25.9% Moderate: 31.3% Low: 34.8%	Medical Records *n* = 814 reported injuries (34.9% overuse injuries, 11.6% serious overuse injuries, 23.8% acute injuries)	Athletes with a higher degree of sports specialisation and were more likely to report serious overuse injuries (OR: 2.62, p<0.01) and acute injury (OR: 1.21, p=0.02) when compared to those with a lower degree of specialisation Adjusted for exposure: No
Moseid et al., 2019	Prospective cohort study	*N* = 259 (gender not specified) Elite athletes from Sport Academy High Schools Mean age not specified (range 15-16)	Any	Single sport or multisport Single sport: 48% Multi-sport: 52%	Specific injury outcome scale *n* = 121 reported health problems	No significant association between specialisation level and risk of injury (OR = 1.06, adjusted *p* =0.66) over 6 months Adjusted for exposure: Yes
Sugimoto et al., 2019	Cross-sectional study	*N* = 236 (100% female) American high school athletes Mean age not specified (range 12-18)	Any	Single sport or multisport Single sport: 25.4% Multi-sport: 74.6%	Medical Assessment	No significant association between specialisation and likelihood of reporting a lower extremity overuse injury, after adjusting for sport volume (aOR = 0.727, p=0.558). However, mean weekly hours of training was found to be an independent risk variable for greater likelihood of lower extremity overuse injury (aOR = 1.091, p=0.034). Adjusted for exposure: Yes

Table 2 – Association between specialisation and physical capability

Study	Study design	Participants	Sport	Classification method	Outcome measure used	Main study outcome
Gorman et al., 2012	Case-control study	*N* = 184 (26% female) American high school athletes Mean age 15.7 years (range not specified)	Any	Single sport or multi-sport Single sport 50% (cases) Multi-sport 50% (controls)	Y-balance test	No significant association between specialisation and YBT reach score (p = 0.98) or asymmetry on any of the three directions tested.
Beese et al., 2015	Cross-sectional	*N* = 40 (100% female) American high school athletes Mean age 15.2 years (range not specified)	Soccer	Single sport or multi-sport Single sport: 53% Multi-sport: 47%	Landing Error Scoring System	No significant association between specialisation and LESS scores in adolescent female soccer players (6.84 ± 1.81 vs 6.07 ± 1.93, p = 0.15)
Miller et al., 2017	Cross-sectional study	*N* = 295 (60.3% female) American high school athletes Mean age 15.6 years (range 13-18)	Basketball Soccer Volleyball (women only) Tennis	Single sport or multi -sport Three-point scale Six-point scale Single sport: 28.4% Multi-sport: 71.6%	Anterior reach of Y-balance test - asymmetry between limbs	Athletes that are considered single sport specialised displayed significantly greater asymmetry on the anterior reach of the Y balance test compared to multi-sport athletes (*p* = 0.015).

DiStefano et al., 2018	Cross-sectional study	*N* = 355 (66% female) Young American athletes Mean age 11 ± 2 (range 8-14)	Soccer Basketball	Single sport or multi-sportth Three-point scale Single-sport: 25.6% Multi-sport: 74.4%	Landing Error Scoring System	The multi-sport group were 2.5 times as likely to categorised as having good control compared to the single sport group ($p < 0.01$)
Sugimoto et al., 2019	Cross-sectional study	*N* = 236 (100% female) American high school athletes Mean age not specified (range 12-18)	Any	Single sport or multisport Single sport: 25.4% Multi-sport: 74.6%	Joint ROM Muscular strength Vertical Jump Front Plank	Multi-sport athletes were more likely to exhibit better R knee flexion ROM, bilateral ankle plantarflexion ROM and bilateral knee extensor strength compared to single sport athletes.

2.4 The association between specialisation and injury

There is some evidence of a positive association between specialisation and injury history in adolescent athletes (Bell et al., 2016; Buckley et al., 2017; Hall et al., 2015; Jayanthi et al., 2011; Jayanthi et al., 2015; Jayanthi et al., 2018; McGuine et al., 2017; Pasulka et al., 2017; Post et al., 2017; Post et al., 2017). However, the strength of the associations found is variable and affected by several methodological limitations, as well as variations in definitions of specialisation and injury described in the studies.

The best evidence examining the association between specialisation and injury comes from prospective cohort studies, as only these studies can show a cause-and-effect relationship. A positive association between specialisation and injury history was found in a prospective cohort study by McGuine et al (2017), where 1544 high school athletes were monitored over a school year, with sport exposure and injuries recorded by an athletic trainer. The study demonstrated that adolescents were significantly more likely to sustain a lower extremity injury (LEI) if they were moderately (Hazard Ratio (HR): 1.51) or highly (HR: 1.85) specialised compared with athletes in the low specialisation group, even after controlling for other potential risk factors such as gender, competition volume, previous LEI history, and age. This study also found that athletes in the high specialisation group were significantly more likely to sustain a chronic LEI (HR: 4.74) than athletes in the low specialisation group. Conversely, no significant association between specialisation and medical withdrawal from tennis matches was demonstrated in a four-week prospective study (Jayanthi et al., 2011). Likewise, a recent prospective cohort study of 259, 16-year-old, elite athletes found no association between specialisation and injury over the following six -months, once the data had been adjusted for sex, sport category and training load (Moseid et al., 2019).

Prospective studies are thought to create the best evidence when examining injury risk, however these studies can be affected by the length of the observation period. A longer observation period may identify more injuries, which may strengthen the association between injury and specialisation, as seen in the study by McGuine et al (2017), where they followed subjects for an entire school year. Whereas a shorter observation period, in this case six months (Moseid et al., 2019) or four weeks (Jayanthi et al., 2011) may result in an insufficient number of injuries reported to establish a clear relationship. On the other hand, a recent prospective study found no association between early sport specialisation (<12 years old) and increased injury history, after adjusting for sport volume and sport type (Moseid et al., 2019).

Further support for the association between specialisation and injury has been demonstrated in larger case-control studies. However, the authors described their methodologies as case-control studies despite not matching cases and control on age, gender or sport type (Jayanthi et al., 2015; Pasulka et al., 2017; Post et al., 2017). Therefore, it becomes difficult to make direct comparisons between the case and control groups due to the possibility of confounding factors that were not controlled for. An important confounder appears to be gender, with recent research demonstrating that adolescent female athletes are twice as likely to report an overuse-type injury, compared to age matched males. The authors concluded that this was partially due to sport choices, with male athletes tending to choose more team based, contact sports and females electing for more individual, technical sports, which is also where increased levels of specialisation are commonly seen (Jayanthi et al., 2015). Information from a sport participation questionnaire and medical records from 822 adolescent athletes that attended a sport medicine clinic due to an injury (cases) was compared with information from 368 adolescent athletes that were uninjured but attending medical practices for wellness checks (controls). Analysis of the data revealed that athletes that specialised in a single sport had higher odds of reporting an injury (Odds Ratio (OR) 1.27) after controlling for age and time participating. The strongest association was in the highly specialised participants, who had the highest odds for association with any injury (OR 1.58), an overuse injury (OR 1.50), or a serious overuse injury (OR 2.25). However, the study found no significant association between high specialisation and acute injury history. This study did have limitations however, as the control group was significantly smaller than the study group and was not age matched, therefore introducing possible confounding factors and making direct comparisons between groups difficult (Jayanthi et al., 2015). Furthermore, responses to a questionnaire from 1190 athletes found that single-sport specialised athletes that participated in individual sports reported greater rates of overuse injuries, but lower rates of acute injuries compared with single-sport specialised athletes in team sports (Pasulka et al., 2017). Likewise, results from a questionnaire from 2011 young athletes showed that highly specialised athletes were more likely to report a previous injury of any kind (OR 1.59) or an overuse injury (OR 1.45) in the previous 12 months compared with athletes in a low specialisation group, independent of age, sex and weekly organised sport volume (Post et al., 2017). Despite limitations within the research methodologies, these studies contribute to the body of evidence that specialisation may be associated with an increased risk of injury and overuse injury in adolescents.

A positive association between specialisation and injury has also been demonstrated in three retrospective cohort studies (Hall et al., 2015; Jayanthi et al., 2011; Jayanthi et al., 2018). A study of 540 elite junior tennis players revealed a significant association between specialisation and reporting a tennis related injury or illness in the past year (OR 1.55) (Jayanthi et al., 2011). This study used a very

restrictive and specific definition of injury, including any injury that caused the medical withdrawal from a competitive tennis match. This may have caused an under-reporting of injuries, as athletes may have been able to continue playing with some injuries. In addition, information gathered from 546 female, high school athletes participating in basketball, soccer and volleyball demonstrated that single sport specialised athletes reported a 1.5-fold greater incidence of patello-femoral pain (PFP) and a 4-fold greater risk of developing an overuse apophysitis such as patellar tendinopathy or Osgood Schlatter disease compared to multi-sport athletes (Hall et al., 2015). Moreover, a study of 1190 injured adolescent athletes revealed that after accounting for age and weekly sport volume, highly specialised athletes were more likely to report a serious overuse injury (OR 1.50) (Jayanthi et al., 2018). Conversely, a retrospective cohort study used survey responses from 3,276 athletes regarding their sporting participation over the previous 12 months, broken up into four seasons. No association was found between reported overuse injuries and whether the athlete was considered single or multi-sport. However, this study did demonstrate that athletes that participated in organised sport in all four seasons were significantly more likely to report an overuse injury (OR 1.42) compared to athletes that played sport in less than four seasons. The authors suggested that a risk factor for overuse injury could be related to playing sport all year-round, rather than specialising in a single sport (Cuff, Loud, & O'riordan, 2010). This study was limited by a low response rate of 44%.

Finally, several retrospective cross-sectional studies have found a positive association between specialisation and injury (Bell et al., 2016; Buckley et al., 2017; Post et al., 2017). Highly specialised athletes have been shown to be more likely to report a history of overuse knee injuries compared with those in the moderate or low specialisation groups (Bell et al., 2016). Similarly, when responses to a questionnaire from 503 high school athletes were compared to those from collegiate and professional athletes, current high school athletes recalled a statistically higher incidence of sustaining an injury that they attributed to specialising in one sport (Buckley et al., 2017). However, the current youth sport environment may be different today, and may place more emphasis on early specialisation and higher competition volume than previously (Buckley et al., 2017). This may make it difficult to make direct comparisons between current high school athletes and current collegiate and professional athletes. This study did have the strength of a high number of participants, with 3090 surveyed over the three groups (Buckley et al., 2017). Furthermore, cross-sectional research performed on 1544 high school athletes from 29 high schools demonstrated that athletes were more likely to report previous LEI if they were highly specialised. (Post et al., 2017). Conversely, a recent cross-sectional study found no significant association between playing one sport and increased reported injuries (Kahlenberg et al., 2016). The authors concluded from the study, that a higher total number of hours of sport participation was significantly associated with an increased injury history, as well as playing a

contact sport (Kahlenberg et al., 2016). This study was limited by a low response rate of 27%, which may decrease the power of the research findings. More recently, a study of 236 female high school athletes found no significant association between specialisation and the likelihood of reporting a lower extremity overuse injury, after adjusting for sport volume (adjusted Odds Ratio (aOR = 0.727). However, the study's findings revealed that mean weekly hours of training was an independent risk variable for greater likelihood of lower extremity overuse injury (aOR = 1.091) (Sugimoto et al., 2019). The authors concluded that weekly sport volume was a greater factor than specialisation in increased injury risk, however the study did not examine the type of training that occurred throughout the week e.g. resistance training versus endurance versus sport-specific training.

These findings do highlight the important confounding factor of sport participation volume, which should be considered in future reasearch. There have been several volume based guidelines suggested for adolescent sport. One commonly used guideline recommends that children do not participate in the same sport for more than 8 months of the year (Jayanthi et al., 2015). A second guideline suggests that youth should not exceed a 2:1 ratio of organised weekly sport to recreational 'free-play'. A study involving 1190 adolescent athletes revealed that athletes with serious overuse injuries had 1.70 times the odds of exceeding this ratio compared to participants without serious overuse injuries, after adjusting for age (CI, 1.12-2.56; $p \leq .01$) (Jayanthi et al., 2015). This finding was replicated in a recent study of 914 New Zealand children (10-13 years) that rpeorted those exceeding the ratio were again more likely to report a history of gradual onset injury (OR = 1.52) (McGowan et al., 2020). Free-play is thought to provide some protective effects by providing variety in movement patterns and reducing the likelihood of gradual onset injuries.

In summary, the majority of the research is supporting the idea that specialisation is positively associated with an increased risk of injury in the adolescent population. Collectively, these results could be suggestive that guidelines for adolescent sport participation should be updated, to encourage participation in a variety of sport and physical movement patterns. However, there is a substantial variation in the results across the included studies, which makes direct comparison between studies and synthesis of the results difficult. This may be partially due to the disparity seen in two key areas. Firstly, there is variation in the methods used to classify the level of specialisation of the participants. Secondly, the definition of injury and likewise the variation in the method of injury data collection may affect the results of the research.

2.4.1 Key limitations in the evidence

2.4.1.1 Specialisation Classification

It is difficult to make direct comparisons between studies due to the variation in classification methods used to determine the specialisation level of the participants. Eight of the included studies used a three-point scale to categorise the participants as low, moderate or highly specialised (Bell et al., 2016; Jayanthi et al., 2015; Jayanthi et al., 2018; McGuine et al., 2017; Miller et al., 2017; Pasulka et al., 2017; Post et al., 2017; Post et al., 2017). The remaining 13 studies used simpler methods and categorised participants using a dichotomous scale as either single-sport (specialised) or multi-sport (not specialised) athletes (Beese et al., 2015; Bell et al., 2016; Buckley et al., 2017; Cuff et al., 2010; DiStefano et al., 2018; Gorman et al., 2012; Hall et al., 2015; Jayanthi et al., 2011; Kahlenberg et al., 2016; Pasulka et al., 2017; Miller et al., 2017; Moseid et al., 2019; Sugimoto et al., 2019). At the time of this review, the authors could not find any published data on the validity or reliability on any of the methods of specialisation classification. A recent study examining the prevalence of sports specialisation based on two classification methods found no association between a self-classification method and a three-point scale, with less athletes self-classified as specialised than when the three-point scale is used in the same population (Bell et al., 2016). This highlights the need for future research to investigate how specialisation is most appropriately classified.

The main issue appears to be the definition of specialisation used in each method and whether or not a dichotomous rating is sufficient or additional categories are needed. When using the dichotomous, single-sport versus multi-sport method, studies use several different criteria or questions to determine specialisation level. One study categorised participants based on whether they had been involved in one sport year-round or multiple sports year-round (Cuff et al., 2010). A tennis-specific study categorised their participants as specialised if they only played and competed in tennis in the last year (Jayanthi et al., 2011). In addition, one study used a six-point questionnaire to categorise participants as specialised (Miller et al., 2017). This scale was developed by Jayanthi et al (2011) and is comprised of the following six questions; i) Can you pick a main sport?, (ii) Did you quit other sports to focus on a main sport?, (iii) Do you train >8 months per year in your main sport?, (iv) Do you train more than 75% of the time in your primary sport?, (v) Do you train to improve skill and miss time with friends as a result?, and (vi) Do you regularly travel out of state for your primary sport? The scale is dichotomised to single or multi-sport, with a positive response to four or more questions classifying the athlete as specialised. The six-point scale was later simplified to the three-point scale by Jayanthi et al (2015).

Contrary to the variety of criteria used in the literature to differentiate single sport athletes from multi-sport athletes, when using the three-point scale, studies used the same three questions and scoring method. The three-point method of classification was developed by Jayanthi et al (2015) in an attempt to provide a standardised method of categorising specialisation and to provide more detail about the level of specialisation of the athlete, rather than being classified as purely specialised or not. The three-point classification scale is based on the commonly used definition of sport specialisation as "year-round intensive training in a single sport at the exclusion of other sports". The three-point scale uses answers to three survey questions: (i) Can you pick a main sport?, (ii) Did you quit other sports to focus on a main sport? And (iii) Do you train >8 months per year in your main sport? The sum of these questions is then used to assign a degree of specialisation with three categorises, high, moderate and low.

Recent research has found that the classification method used can be a significant factor in the results of the study (Bell et al., 2016). It was demonstrated that specialisation was less prevalent when using a dichotomous scale, with only 26.2% of athletes that self-classified as multi-sport categorised as low specialisation according to the three-point scale. As a result, when the athletes were categorised as single or multi-sport, no association was found between specialisation level and injury. Whereas, when the three-point scale was used, a significant association between specialisation level and injury was found. In addition, when using a dichotomous scale, results were influenced by the age and gender of the participant, whereas these confounding factors did not influence results when using the three-point scale. Interestingly, the four studies that found no association between specialisation and injury used the single sport versus multi-sport method of classification (Cuff et al., 2010; Kahlenberg et al., 2016; Moseid et al., 2019; Sugimoto et al., 2019). Similar issues were demonstrated when comparing a two-point, self-classification method with the three-point and six-point scales (Miller et al., 2017). A large variation in the proportion of specialised versus multi-sport athletes was seen, with 28.4% of participants self-classified as single-sport when using a dichotomous scale, 36.2% were considered highly specialised with the three-point scale, and 54.9% were classified as single-sport when using the six-point questionnaire.

As there has been no validity testing done on any classification method, it is difficult to conclude which is best. Although the single sport versus multi-sport classification can appear simpler, the three-point classification method may be more reliable and valid due to the standardised questions and it appears to be less affected by confounding factors such as sex or age (Bell et al., 2016). The three-point scale also gives researchers more detail about the level of specialisation. Consequently, this may threaten the validity of any study that uses a dichotomous scale. Based on the current evidence, when

classifying specialisation level of athletes, the use of the three-point classification appears to be more beneficial.

2.4.1.2 Injury Definitions

In the studies included in this review, there was a lot of variation in the definition of injury and how the injury data was collected. This is a factor which makes it difficult to make direct comparisons between the results of the included studies and/or to pool data across studies. Injury definitions will be categorised into four categories: (i) Time loss, (ii) Medical attention, (iii) Medical records, and (iv) Specific injury outcome scales. Injury data was mostly acquired through self-report questionnaires (Bell et al., 2016; Buckley et al., 2017; Jayanthi et al., 2011; Kahlenberg et al., 2016; Moseid et al., 2019; Pasulka et al., 2017; Post et al., 2017; Sugimoto et al., 2019). Moseid et al, (2019) defined an injury as affecting the musculo-skeletal system, as well and concussions. Some studies only included injuries that caused time-loss, including injuries that caused the participant to miss at least one week of sport (Buckley et al., 2017; Cuff et al., 2010; Jayanthi et al., 2011; Post et al., 2017) while others only included injuries that required attention from a health professional (Buckley et al., 2017; Cuff et al., 2010; Jayanthi et al., 2011; Kahlenberg et al., 2016; McGuine et al., 2017; Post et al., 2017; Sugimoto et al., 2019). Two studies used outcome measures to classify injury, including the Anterior Knee Pain Scale and the International Knee Documentation Committee (IKDC) form (Hall et al., 2015) and an online OSTRC questionnaire (Moseid et al., 2019). Some studies used access to medical records to classify injuries or gain diagnostic data (Hall et al., 2015; Jayanthi et al., 2015; Jayanthi et al., 2018; Pasulka et al., 2017).

In addition, some studies have further differentiated between acute and overuse injuries and some further defined serious overuse injuries (Cuff et al., 2010; Jayanthi et al., 2015; Jayanthi et al., 2018; Moseid et al., 2019; Pasulka et al., 2017). Acute injuries were often defined as being related to a single, traumatic event while overuse injuries were defined as gradual onset without a specific sports-related event (Jayanthi et al., 2015; Jayanthi et al., 2018; Moseid et al., 2019; Pasulka et al., 2017). Serious overuse injuries were defined as those overuse injuries for which a physician recommended treatment of longer than one month of rest from sports (Jayanthi et al., 2015; Jayanthi, et al., 2018; Pasulka et al., 2017). Specialising in one sport is likely to expose adolescents to more repetitive forces, such as overhead shoulder movements in tennis, throwing sports and swimming. This may place the athlete at an increased risk of an overuse type of injury (Buckley et al., 2017). However, it is difficult to see the rationale of how specialisation could influence acute injury. Acute injuries are often separated into contact and non-contact injuries. Contact injuries are likely more related to sport-type and volume,

for example an athlete is more likely to sustain a contact injury playing rugby compared to tennis. Non-contact injuries may be more influenced by aspects of neuromuscular control such as strength and landing technique, for example, knee valgus angle on landing has been shown to be strongly associated with risk of ACL rupture in young female athletes (Hewett et al., 2005; Nilstad, Andersen, Bahr, Holme, & Steffen, 2014; O'Kane et al., 2017). This was highlighted in two studies where highly specialised participants showed increased risk of overuse injury, but there was no association shown between specialisation and acute injury (Jayanthi et al., 2015; Pasulka et al., 2017). When separating acute and overuse injuries, results could be affected by the method of recruitment used in the study.

Potential bias can arise from various stages throughout the research process. The recruitment process is one aspect that can contribute to bias. Studies that recruited participants from specialist medical centres suggested that this may introduce selection bias. Acute injuries may be more likely managed either in a primary health service or urgent care facility, therefore recruiting from a specialist centre may overestimate overuse type injuries (Jayanthi et al., 2015; Jayanthi et al., 2018; Pasulka et al., 2017). This method of recruitment may also limit how applicable the results are to the general adolescent population, as the lower socio-economic status (SES) population may have less access to medical care, especially from a specialist centre (Hall et al., 2015).

Furthermore, bias can arise from the method of injury data collection. Of the studies that used participant self-report measures of injury, all stated that recall bias was a potential limitation to the research (Bell et al., 2016; Buckley et al., 2017; Cuff et al., 2010; Hall et al., 2015; Jayanthi et al., 2011; Jayanthi et al., 2018; Kahlenberg et al., 2016; McGuine et al., 2017; Moseid et al., 2019; Post et al., 2017 Post et al., 2017). Quality of data from participant recall relies firstly on the athlete seeking medical attention and a proper diagnosis being made, and secondly that the athlete has an adequate understanding of the injury and diagnosis, enough to convey this information to the researcher (Cuff et al., 2010). In the adult population, research has demonstrated accuracy of self-report data if the injury has occurred in the last four weeks (Valuri et al., 2005) however, the number injuries will be underestimated if a 12 month recall period is used (Gabbe et al., 2003). In the adolescent population, recall of injuries has been shown to be accurate for injuries in the previous week, but no research has been done over longer time periods (Grimmer et al., 2000). Overall, it appears that self-report of injuries from young participants may be limited by recall bias. Some studies attempted to control for recall bias by introducing a health professional to review the self-report data (McGuine et al., 2017; Post et al., 2017). Overall, it appears that self-report measures may introduce a potential source of bias. Accessing medical records and providing assessment from a health professional may be useful strategies to control for recall bias and improve the validity and reliability of the results.

2.5 The association between specialisation and physical capability

At the time of this review, there has been very little research examining the relationship between specialisation and physical capability. Several outcome measures exist that can evaluate components of physical capability or neuromuscular control, including range of motion (ROM), strength, balance and landing performance. There is disparity in the current literature around association between specialisation and physical capability, with some studies finding an association with their chosen outcome measure (DiStefano et al., 2018; Miller et al., 2017; Sugimoto et al., 2019) and others concluding there is no association (Beese et al., 2015; Gorman et al., 2012).

Two studies used portions of the Y-balance test to evaluate balance (Gorman et al., 2012; Miller et al., 2017). The Y-balance test is a simplified version of the Star Excursion Balance Test (SEBT) which has been shown to be valid and reliable (Robinson & Gribble, 2008). Poor performance on the SEBT has been shown to be associated with an increased risk of a variety of lower extremity injuries (Butler et al., 2013; Gribble et al., 2012; Plisky et al., 2006). Specifically, performance of the anterior reach (distance and asymmetry) has been shown to have the most consistent relationship with increased injury risk (Gonell et al. 2015; Smith et al., 2015). Increased asymmetry of the anterior reach has been shown to be associated with specialisation (Miller et al., 2017). However, the results varied depending on the classification method used to determine specialisation level. When the two-point method was used they found that single sport athletes were significantly more likely to exhibit greater asymmetry (3.0cm vs 3.69cm). When the three-point scale was used, participants in the moderately specialised group displayed the greatest asymmetry compared to the high or low specialisation groups (low; 2.64cm, moderate; 3.80cm, high; 3.11cm). Finally, when a six-point scale was used, single-sport athletes displayed significantly greater asymmetry compared to multi-sport athletes (3.59cm vs 2.67cm). On the contrary, in a case control study, asymmetry and reach distance were shown to have no association with specialisation (Gorman et al., 2012). Participants in this study were matched on age, gender and sport-type. Athletes were free from injury at the time of testing; however, no injury history was taken which may have had an impact on the results. This study also used the two-point scale to classify specialisation level, which may under-estimate the specialisation level of the athletes when compared to the three-point scale.

Two cross-sectional studies used the Landing Error Scoring System (LESS) to examine neuromuscular control with landing and any association with specialisation (Beese et al., 2015; DiStefano et al., 2018). The LESS is a valid and reliable clinical movement analysis tool (Padua et al., 2009), a low score (less errors) has been shown to be predictive of low risk of ACL injury in youth soccer players (Padua et al., 2015). There was variation in the results of the two studies, with one finding an association between

specialisation and LESS scores, demonstrating that the multi-sport group were 2.5 times as likely to have 'good' control compared to single-sport athletes. The authors suggested that sport sampling could be a means of improving neuromuscular control, which may have a protective effect, reducing the risk of injury in adolescent athletes. On the other hand, LESS scores have been demonstrated to have no significant association with specialisation level (Beese et al., 2015). This study was relatively small, with only 40 participants, most of which scored in the 'moderate' or 'poor' category. This study was also limited by the small participant population, all of which were female. Additionally, several athletes were tested immediately following a soccer practice, which could introduce fatigue as a confounding factor for the LESS score.

Finally, a recent cross-sectional study found an association between specialisation and joint range of motion (ROM) and muscular strength (Sugimoto et al., 2019). Knee and ankle joint ROM were measured using goniometry and muscle strength tests of knee flexors, knee extensors, hip abductors and hip adductors were performed using a hand-held dynamometer. Of all the tests performed, it was demonstrated that multi-sport athletes were more likely to exhibit greater ROM with right knee flexion, bilateral ankle plantarflexion and bilateral knee extensor strength compared to single sport athletes.

2.6 Conclusion

The purpose of this review was to examine the association between specialisation and injury and to investigate the association between specialisation and physical capability. This review revealed some evidence of a positive association between specialisation and injury history in adolescent athletes (Bell et al., 2016; Buckley et al., 2017; Hall etal., 2015; Jayanthi et al., 2011; Jayanthi et al., 2015; Jayanthi et al.,, 2018; McGuine et al., 2017; Pasulka et al., 2017; Post et al., 2017; Post et al., 2017). Collectively, these results could imply that adolescents should be educated on the risks of specialisation and guidelines put in place to recommend participation in a variety of sporting activities. However, this review also found significant disparity in the strength of the associations found, which were affected by several methodological limitations, including a lack of prospective research, as well as the variation in definitions of specialisation and injury used in the studies. An example of this is the differences seen in association between specialisation and either acute or overuse injury. The rationale for an association between specialising in one sport and sustaining an overuse injury is sound, with an increase in repetitive movements at a time in development where tissues may be vulnerable. However, rationale for how specialisation may influence acute injury is less robust as there are far more factors involved. Furthermore, there is limited evidence of an association between specialisation and physical capability. A large variation is seen in the results, with some studies finding an association

with their chosen physical outcome measure (DiStefano et al., 2018; Miller et al., 2017; Sugimoto et al., 2019) and others concluding there is no association (Beese, et al., 2015; Gorman et al., 2012). Further research needs to be done in this area and should focus on using a standardised, three-point method of classifying specialisation level, as well as limiting recall bias of injury history. This could be performed by verifying injuries via accessing clinical records or including assessment by a health professional. Further research examining the effects of specialisation on neuromuscular control is also needed with a focus on reliable outcome measures that examine various aspects of neuromuscular control, including balance, range of motion, strength and movement quality.

Prelude to Chapter 3

A narrative review of the literature found some evidence of a positive association between specialisation and injury history in adolescent athletes. However, there was a large variation in the strength of the association found and this was affected by several methodological factors including the definitions of specialisation and injury. Specifically, there is a current lack of research in NZ adolescents older than 12 years old. Therefore, a cross-sectional survey study was conducted to investigate the associations between sport specialisation and injury history. Furthermore, there is a lack of research in the setting high-performance academy setting, a fairly recent phenomenon in adolescent sport. Therefore, the study included investigation of associations between specialisation and participation in a performance-based sport academy.

Chapter 3: The association between sport specialisation and injuries in adolescents

3.1 Abstract

Objective: To investigate the associations between single sport specialisation and injury history in New Zealand adolescents and to examine the differences in specialisation level and injury between high school sport and performance-based academy sport athletes.

Design: Cross-sectional survey study

Methods: Adolescents (age 12-16) from five NZ high schools and one performance-based academy were invited to complete a questionnaire capturing sport specialisation level (low, moderate or high), sport participation volume and injury history. Multiple logistic regression was used to investigate associations between variables.

Results: One hundred and ninety-nine participants (136 female) completed the questionnaire. After adjusting for age, sex, hours of weekly sport and hours of free-play, the odds of reporting an injury were not significantly higher for specialised adolescents compared to adolescents categorised as low specialisation (OR = 2.1; CI = 0.7-6.0; p = 0.179). Participating in more hours of sport per week increased the odds of reporting a time-loss injury (OR = 1.1; CI = 1.0-1.2; p = 0.011). There was a significant association between playing one sport for more than eight months of the year and reporting a time-loss injury (OR=3.2*; p=0.003). Involvement in a performance-based sport academy (n=33) had no association with specialisation level, however participants in the academy group reported higher total weekly sport volume (school group median = 4.5 hours, academy group median = 8 hours, p = 0.006) and were more likely to exceed a 2:1 ratio of weekly hours of organised sport to weekly hours of recreational free-play (OR = 6.8; CI = 2.9-16.0; p = 0.001).

Conclusion: Single-sport specialisation did not increase the odds of reporting a history of injury in this group of adolescents and participation in a sports academy did not increase the chances of being highly specialised. However, increased organised sport participation volume was associated with increased odds of reporting a time-loss injury.

3.2 Introduction

It is well recognised that sport participation during adolescence has many benefits including improved quality of life, self-image and social relationships (Hecimovich, 2004). Adolescent sport participants have been shown to be less likely to smoke and more likely to have better attendance and grades in school (Hecimovich, 2004). There is also evidence that active adolescents are much more likely to remain active into their adult years and exhibit a general decrease in morbidity and mortality, including improvements in bone mineral density, lipid profile, cardiovascular endurance, muscle strength and blood pressure (Brenner, 2007; Hecimovich, 2004; Menschik et al., 2008; Troutman & Dufur, 2007). However, involvement in sport also poses a risk of musculoskeletal injury and it is evident from the literature that acute and overuse injuries are a significant issue in active adolescents (Cuff et al., 2010; Myer et al., 2015; Pakzad-Vaezi & Singhal, 2011; Shee et al., 2017). Additionally, twenty percent of adult elite athletes reported injury as a reason for retiring from their sport, and up to eight percent of adolescents dropped out of sport due to injury or fear of injury (Myer et al., 2015). Importantly, the incidence of injury in adolescents appears to be increasing. An Australian study involving 5,671 children under 15 showed a 61% increase in sport-related injuries between 2003 and 2012 (Shee et al., 2017) and in Canada a study which involved 27,466 sport-related injuries indicated a 28% increase between 1992 and 2005 (Pakzad-Vaezi & Singhal, 2011). In New Zealand, national insurance data from the Accident Compensation Corporation (ACC) showed a 60 percent increase in sports-related injuries in the 10-14 year age-group over the past decade (Wilson, 2019). These increases have been partly attributed to an increase in sport specialisation and the associated increases in training volume and intensity typically seen in adolescents (Myer et al., 2015).

Sport specialisation has been commonly defined as year-round intensive training in a single sport at the exclusion of other sports (Jayanthi et al., 2015). The current trend toward earlier sports specialisation and year-round training has raised concerns that these factors may be increasing the risk for injury. Although evidence is conflicting there have been a number of recent studies that have reported increased injury risk in more highly specialised youth athletes (Bell et al., 2016; Buckley et al., 2017; Hall et al., 2015; Jayanthi et al., 2011; Jayanthi et al., 2015; Jayanthi et al., 2018; McGuine et al., 2017; Pasulka et al., 2017; Post et al., 2017; Post et al., 2017). The potential link between sport specialisation and injury has been examined in young athletes aged 10-13 years in New Zealand (McGowan et al., 2020). This study found that there was a high degree of specialisation in this age group but demonstrated no significant association between specialisation and injury. The authors suggested that the lack of association may be related to the age of the participants, with the selected age group potentially being too young to exhibit the effects of early specialisation. This research

highlighted the need for further research in the area of sport specialisation and injury in NZ adolescents older than 13.

At the time in their lives when adolescents are developing and growing the most rapidly, it is important to have well informed guidelines around sport participation. In order to optimise injury prevention strategies, it was important to examine sport participation in two key settings. One setting was high school sport, where the majority of active adolescents participate in sport and the other setting was a performance-based sports academy, a more recent phenomenon in adolescent sport and potentially a contributing factor to the high levels of sport specialisation seen in young athletes. Thus, the primary aim of the study was to examine the association between specialisation level and injury history and a secondary aim was to investigate if participation in a performance-based academy was associated with differences in specialisation and/or sport participation.

3.3 Methods

Data was collected from five New Zealand high schools and one school age high-performance sport centre during the 2019 and 2020 school years. Schools were invited to participate based on a previous relationship with the local physiotherapy clinics in each area and all of the invited schools agreed to participate in the study. Three of the schools included were privately funded and two were publicly funded. School size based on the number of enrolled students in 2019 ranged from 301 to 1,280 students. All schools were in the high decile range of 8-10 (measure of community socioeconomic status). The high-performance sport centre was based at a community fitness centre and was focused on providing a high-performance programme to developing school age athletes in a range of sports. Following agreement from the schools and sport academy, potential participants were recruited via an anonymous survey either filling in a paper copy or via an online survey system commonly used by the schools, using a weblink to access the survey via SurveyMonkey or Qualtrics. All students were provided with a study information sheet (Appendix 2). To be included in the study, students needed to be in years 9-11 (age 12-16) at high school and actively participating in some type of organised sporting activity. Ethical approval was granted for this study by the AUT University Ethics Committee (AUTEC), under application number 19/122 (Appendix 4). All participants and their guardians provided assent/consent prior to participation (Appendix 1).

3.3.1 Questionnaire

Information was gathered about the school year level and gender of the participants. A questionnaire with 13 questions was used (Appendix 3). This questionnaire was based on previous research by

McGowan et al (2020) which examined specialisation and injury associations in NZ adolescents aged 10-13. Participants were asked to report on all organised sport they had participated in over the last 12 months, including the type of sport, the season in which it was played, and the hours of sport performed each day. Additionally, participants were asked to report on the hours of recreational free play (including unstructured and unsupervised physical activity) they participated in on average per week. Sport specialisation was determined using a previously used three-point scale (Jayanthi et al., 2015). The scale included the following questions: (1) Can you choose one main sport that is more important than the others? (2) Did you train/compete more than 8 months out of the year in one sport? (3) Have you only ever trained/competed in one sport? (4) Have you quit all other sports to focus on one main sport? One point was given to each affirmative answer and specialisation classified as low (score = 0-1), moderate (score = 2), or high (score = 3) (note: it is not possible to score a point for both questions 3 and 4, thus the maximum score is 3). Acceptable reliability of this scoring system (ICC=0.85) has been reported previously (McGowan et al., 2020). Participants that were considered highly specialised on the three-point scale but reported participating in only 2 hours of sport or less per week (n=7) were re-allocated to the low specialisation group as the authors felt that participation in two hours of sport did not meet the commonly accepted definition of specialisation which includes intensive training (Jayanthi et al., 2015). Finally, participants were asked about their history of injuries over the last 12 months, including details on location and whether they were able to continue to participate in sport or needed time off. Injuries that caused the participant to take time off sport were classified as time-loss injuries.

3.3.2 Statistical Analysis

Categorical variables such as gender, school year, specialisation level and injuries were summarised using frequencies and proportions (%). Continuous variables such as sport participation volume (hours) were summarised using medians and range or means and standard deviations. The main explanatory variables investigated included specialisation category (low, moderate or high) and sport participation volume measures including hours per week and whether the participant exceeded a 2:1 ratio of weekly organised sport hours to weekly hours of recreational free play (recoded as a categorical variable “yes” or “no”). Additional variables, which were considered potential confounders based on previous studies (Jayanthi et al., 2015; McGuine et al., 2017; Post et al., 2017) included school year and gender. These potential confounding variables were controlled for in the logistic regression.

Multiple logistic regression (block entry method) was used to examine the association between specialisation category and time-loss injury and between sport participation volumes and time-loss injury, while adjusting for potential confounders. Unadjusted and adjusted odds ratios (OR) with 95%

confidence intervals (CI) were calculated. A Kruskal-Wallis test was used to compare sport volumes between specialisation levels. Chi-square for independence testing was used to compare categorical variables between the school and academy groups (including specialisation, exceeding a 2:1 ratio of weekly organised sport hours to weekly recreational free-play hours and playing one sport for more than 8 months of the year) whereas Mann-Whitney U testing was used to compare continuous variables such as weekly hours of organised sport and weekly hours of recreational free play. Statistical significance was set a priori at $p \leq 0.05$. All analyses were performed using the Statistical Programme for Social Sciences (SPSS) (IBM SPSS, Chicago), version 25.

3.4 Results

A total of 199 participants (136 female) completed the questionnaire and were included in the study (8% Year 9, 10% Year 10, 31% Year 11 and 52% Year 12). A total of 171 (86%) of participants reported sustaining an injury in the past 12 months (time-loss n= 139, other n=145). A total of 362 unique injuries were reported, of which 58% were to the lower limb, 25% the upper limb, 12% the torso and 5% the head or face. The most common injury sites included the ankle (n=62), knee (n=58) and hip/thigh (n=48). A total of 35 different sports were recorded across all participants, of which 21 were considered individual sports and 14 were considered team sports. The most popular sports included netball (n=65), football (n=61), tennis (n=49) and hockey (n=46). The number of sports played per participant ranged from one to six.

Using the three-point classification method, 70 (35%) of participants were classified as low specialisation, 94 (47%) moderate specialisation and 35 (18%) high specialisation. Based on univariate logistic regression participants in the high specialisation group were 3.2 times more likely to report a time-loss injury than those in the low specialisation group (p=0.002) (refer to Table 3). However, after adjusting for relevant confounding variables (including gender, school year, exceeding a 2:1 ratio of weekly organised sport hours to weekly recreational free-play hours and hours of weekly sport volume), there was no significant association between specialisation level and reporting a time-loss injury (refer to Table 3) or any injury (refer to Table 4).

Table 3: Association between specialisation level and history of time-loss injury

Specialisation Category	Unadjusted* OR (95% CI)	*p* Value	Adjusted**OR (95% CI)	*p* value
Low		**0.048**		0.379
Moderate	1.744 (0.903-3.367)	0.098	1.351 (0.673-2.714)	0.397
High	3.222 (1.185-8.765)	**0.022**	2.076 (0.715-6.028)	0.179

OR, odds ratio. $p<0.05$ is statistically significant (**bold font**). *Univariate logistic regression analysis. **Multiple logistic regression models adjusted for gender (categorical), school year level (categorical), exceeding a 2:1 ratio of weekly organised sport hours versus weekly recreational free play hours (categorical) and sport volume (hours per week). The reference group was the low specialisation group.

Table 4: Association between specialisation level and history of any injury

Specialisation Category	Unadjusted OR (95% CI)	*p* Value	Adjusted OR (95% CI)	*p* value
Low		0.075		0.264
Moderate	2.058 (0.88-4.812)	0.096	1.706 (0.704-4.134)	0.237
High	4.5 (0.967-20.933)	0.055	3.193 (0.642-15.894)	0.156

OR, odds ratio. $p<0.05$ is statistically significant (**bold font**). *Univariate logistic regression analysis. **Multiple logistic regression models adjusted for gender (categorical), school year level (categorical), exceeding a 2:1 ratio of weekly organised sport hours versus weekly recreational free play hours (categorical) and sport volume (hours per week). The reference group was the low specialisation group.

The median weekly sport volume across all participants was 5 hours (range 0.5-29.5 hours), whereas the median weekly recreational free-play volume was 4 hours (range 0-25 hours). The low specialisation group reported significantly lower weekly sport volume than the moderate (difference 2.2 hours, p=0.003), and high (difference 3.8 hours, p=0.001) specialisation groups. The median volume in participants that reported a time-loss injury was 5.8 hours while the median in the non-injured group was 3.75 hours. The proportion of participants that exceeded a ratio of 2:1 weekly organised sport hours to weekly recreational free-play hours was 35.7%, however this individually did not have a significant association with injury (OR=0.8; p=0.674). The proportion of participants that exceeded the recommended maximum months (>8) per year in a single sport was 66.5%. There was a significant association between playing one sport for more than eight months of the year and reporting a time-loss injury (aOR=3.2 p=0.003). Additional regression analysis demonstrated a significant association between reporting a time-loss injury and weekly hours of sport volume (p=0.011). For every hour of additional sport volume, participants were 1.13 (95% CI: 1.03-1.24) times more likely to report a time-loss injury. There was no association between weekly hours of sport and reporting any injury (p=0.075).

Although there was no statistically significant association between specialisation level and being involved in a high-performance academy, there was a trend for a higher proportion of highly specialised participants in the academy group (n=33) compared to the school group (n=166). However, participants from the sports academy were 6.8 times more likely to exceed a 2:1 ratio of weekly organised sport hours to weekly recreational free-play hours (p=0.001) (Table 5). Sport volume was also significantly higher in the sports academy group (median 8.0 hours) compared to the school group (median 4.5 hours) (p=0.006).

Table 5: Comparison of specialisation level and sport participation volumes between the performance-based academy group and the school group

	School group (n=166)	**Academy group (n=33)**	**Odds Ratio (95% CI)**	***p* Value**
Low Specialisation	37.3%	24.2%	1.35 (1.24-1.46)	0.187
Moderate Specialisation	47.0%	48.5%	1.03 (-0.01-1.06)	0.319
High Specialisation	15.7%	27.3%	1.74 (1.59-1.88)	0.067
Exceeding 2:1 volume ratio	28.1%	72.7%	6.75 (2.92-15.60)	**0.001**
Plays one sport more than 8 months of the year?	64.7%	75.8%	1.68 (0.71-3.96)	0.302

p<0.05 is statistically significant (**bold font**).

3.5 Discussion

The primary aim of this research was to examine sport specialisation in adolescents and its association with musculoskeletal injury. Being highly specialised in one sport did not significantly increase the likelihood of reporting a history of injury in this group of 12-16-year-old NZ adolescents. These findings are similar to previous research performed in NZ youth aged 10-13 (McGowan et al., 2020). However, the results are contrary to previous research conducted overseas (Bell et al., 2016; Buckley et al., 2017; Hall et al., 2015; Jayanthi, et al., 2011; Jayanthi et al, 2015; Jayanthi et al 2018; McGuine et al., 2017; Pasulka et al., 2017; Post et al., 2017; Post et al., 2017). There are several possible explanations for this, one of which is that this study controlled for sport volume where other studies did not (Bell et al., 2016; Buckley et al., 2017; Jayanthi et al, 2018; McGuine et al., 2017; Post, Bell, et al., 2017). It is possible that specialisation pathways in adolescent sport are driving an increase in weekly sport volume. This increase in weekly hours of sport is often coupled with an increase in intensity, competition/training volume and repetition of similar movement patterns (Buckley et al., 2017). This combination of factors could in turn be what causes an increase in the risk of injury in adolescents.

This study supports the association between injury and increased sport volume that has been seen in previous research (McGowan et al., 2020; Sugimoto et al., 2019). The results of this study indicated that for every hour of additional sport volume, participants were 1.13 times more likely to report a time-loss injury. This result highlights the need for sport volume guidelines in adolescent sport. One commonly used guideline recommends that children do not participate in the same sport for more than 8 months of the year (Jayanthi et al., 2015). Around two-thirds of the participants in this study participated in one sport for more than 8 months of the year, which is similar to findings in previous studies (DiFiori et al., 2014; McGowan et al., 2020). In keeping with previous literature, these adolescents had increased odds of reporting a time-loss injury (McGowan et al., 2020; Jayanthi et al., 2015; Post, Trigsted, et al., 2017). Although playing one sport for more that 8 months of the year is a criteria used in the sport specialisation rating scale, is it obvious that many multi-sport athletes are still exposed to this volume based risk. This may be indicative of changing sporting habits of adolescents. Anecdotal evidence would suggest that the majority of adolescents are not playing one sport in the winter season and then ceasing this sport to play another in the summer season. The sporting seasons appear to be longer than in the past, often with some cross-over where the athlete may be playing two or more different sports in the same week (Caruso, 2016).

A second guideline on sport volume commonly reported is that youth should not exceed a 2:1 ratio of organised weekly sport to recreational 'free-play'. Free-play is thought to provide some protective effects by providing variety in movement patterns and reducing the likelihood of gradual onset injuries. Recent research indicates that recreational free-play in NZ youth is declining (Jelleyman et al., 2019). This reduction in free play has been suggested to be due to an increase in organised sport causing a lack of free time. However, in this study, exploratory analysis found that there was no significant differences in weekly volume of recreational free-play between any of the specialisation groups. Previous research has found a siginificant association between exceeding the recommended 2:1 ratio and sustaining a gradual-onset or overuse injury (McGowan et al., 2020; Jayanthi et al., 2015). In contrast, although this study found that close to a third of the participants exceeded this threshold, it did not increase the likelihood of them reporting an injury. The results of this study may have varied from previous research as we did not separate injuries into 'acute' or 'gradual-onset' and it is difficult to see a strong rationale for how 'free-play' may have any significant protective effects in reducing acute injuries.

The second aim of this study was to examine the differences in specialisation level and sport participation volume between high school sport and performance-based academy sport. To our knowledge this is the first study performed in NZ that compares these two groups and the first investigating specialisation and injury in the performance academy environment. The results of this

study indicate that although there was no statistically significant association between specialisation level and being involved in a performance-based academy, there was an observed trend for a higher proportion of highly specialised adolescents in the academy group. Furthermore, adolescents involved in an academy were more likely to participate in much higher sport volumes and were 6.8 times more likely to exceed the recommended 2:1 ratio of weekly organised sport hours to weekly recreation free-play hours. However, these results may have been affected by a high variation in size of the study groups (33 participants in the academy group versus 167 in the school group). That said, these findings provide preliminary evidence that performance-based academies do alter the sport participation volume of adolescent athletes and this is worthy of further research.

We acknowledge that this study had limitations. The first was related to the methodology used in the research where a cross-sectional study design was used and asked participants to recall retrospective events. This allowed examination of associations between variables, but we were unable to determine causation. With this type of study there was likely an element of recall bias involved. In order to reduce this, a survey that had been designed for younger participants was used and an information sheet was provided for the participant to read before commencing the survey. Due to ethical considerations, the survey was made completely anonymous, this meant that we were unable to collect potentially useful information such as date of birth to calculate exact chronological age and we were also unable to contact the participant following the survey to verify information given about injuries that they sustained over the past 12 months. This meant we were unable to accurately determine if these injuries were acute or gradual-onset. Furthermore, due to ease of access, this research was performed in only two regions in NZ (Hawke's Bay and Kapiti) and the schools that were involved were all high decile, suggesting that these areas tended to be of higher socio-economic status. Therefore, we are unable to determine whether the results apply to the rest of the NZ population. Furthermore, although we were aware that maturation is a likely factor that has the potential to affect injury risk, we did not measure this during data collection. Prospective, longitudinal studies following adolescents through their development are needed to better understand the risk of injury in adolescents from specialisation.

3.6 Conclusion

In this group of 12-16-year-old NZ adolescents there was no significant association between specialisation in a single sport and reporting a history of injury. However, we did find that increased weekly sport volume increased the likelihood of reporting a time-loss injury. In addition, involvement in a performance-based academy was associated with increased sport volumes and decreased

recreational free-play. This study provided an exploratory look into the sport engagements of adolescents in a performance-based academy setting and could be used to inform sport guideline for active adolescents. However, larger scale research is needed to better examine this fairly recent phenomenon in the adolescent sport environment.

Prelude to Chapter 4

Reduced neuromuscular control has been proposed as a mechanism by which single sport specialisation might increase injury risk however there has been limited research in this area. Additionally, the injury data in most studies is at risk of recall bias. Therefore, a cross-sectional study was conducted to examine the association between sport specialisation and performance on the Y-balance test, while also collecting injury data based on physiotherapist diagnosis.

Chapter 4: The association between sport specialisation and balance performance in adolescents

4.1 Abstract

Objective: The primary aim of this study was to examine the association between specialisation and neuromuscular performance, specifically performance on the Y-balance Test. The secondary aim of this study was to examine associations between specialisation and injury history.

Design: Cross-sectional study

Methods: Adolescents (school years 9-11) from five NZ high schools were invited to complete a questionnaire capturing sport specialisation level (low, moderate or high) and injury history in the previous 12 months. Injury diagnoses were confirmed using clinical notes or through examination by a physiotherapist. The Y-balance Test was used to examine balance performance, including composite reach scores (% leg length) in three directions, as well as symmetry between performance on the left and right sides. One-way analysis of variance was used to compare Y-balance performance between specialisation groups. The frequency of injuries in each specialisation group was also reported.

Results: A total of 23 participants (10 female) completed the questionnaire and the Y-balance testing. There was no significant association between Y-balance Test performance and specialisation level *(p*>0.05). Based on observation of descriptive injury statistics, all specialisation groups reported similar frequency of injuries in the past 12 months. The predominant injuries were diagnosed as growth related lower limb injuries. The high specialisation group reported the most gradual onset injuries and least acute injuries.

Conclusion: Single-sport specialisation was not associated with reduced performance measures on the Y-balance Test. Growth-related lower limb injuries are common in this group of NZ adolescents.

4.2 Introduction

It is well recognised that sport participation during adolescence has many benefits including improved quality of life, self-image and social relationships (Hecimovich, 2004). Adolescent sport participation has been shown to have ongoing health benefits into later life, with active adolescents shown to be much more likely to become active adults and show a marked decrease in morbidity and mortality (Brenner, 2007; Hecimovich, 2004, Menschik et al., 2008; Troutman & Dufur, 2007). However, adolescent sport participation has changed significantly over the past decade, both in New Zealand and internationally. (Bergeron, 2010; Sam & Ronglan, 2007). Youth sport is becoming increasingly professionalised and competitive, with more talent identification occurring at younger ages and an emphasis on performance pathways to elite sport (Bergeron, 2010). As a result, there has been a trend towards earlier sport specialisation (intense, year-round participation in a single sport at the exclusion of others) with more frequent, organised, high intensity sport from an early age (Buckley et al., 2017). This is often accompanied by an increased focus on competition with increased volume and frequency of games. (Bergeron, 2010). Sport specialisation and high sport participation volume during adolescence has been linked to increased risk of sustaining injuries, particularly overuse injuries (Brenner et al., 2016; Hall et al., 2015; Jayanthi et al., 2015; McGuine et al., 2017; Post et al., 2017). Injury in adolescents is a concern as it has been reported as a leading cause of drop out from sport, denying the athlete the chance to reap the benefits of ongoing sport participation into adulthood (Myer et al., 2015). Therefore, it is important to investigate the possible mechanisms by which specialisation may increase the risk of injury in adolescents.

One possible explanation for the link between sport specialisation and injury suggests that adolescents that specialise may be denied the benefits of varied activity while facing additional physical, physiological, and psychological demands from intense training and competition (Pediatrics, 2000). Varied activity and movement patterns are thought to allow for optimal development of neuromuscular control, which includes stability, movement quality, strength, flexibility and balance. Having good neuromuscular control may have a protective effect for adolescents in sport and underdevelopment of one or more of the components of neuromuscular control may increase risk of injury (DiStefano et al., 2018). It may be expected that athletes that participate in multiple different sporting activities would be exposed to a greater variety of movement patterns and may develop more adaptable movement strategies. Athletes that choose to specialise in a single sport may be denied the variety in movement patterns and therefore be denied these benefits (Pediatrics, 2000). When compromised neuromuscular control is combined with increased exposure to repetitive forces adolescents that specialise are potentially at greater risk of overuse injury (Buckley et al., 2017).

With the increase in injuries and growing concern over the long-term consequences of injury in adolescents, a number of tools have been developed to assess risk factors for injury such as balance (Gorman et al., 2012). One of these tools is the Y -balance Test which is a reliable and valid derivative of the Star Excursion Balance Test (Robinson & Gribble, 2008) used to evaluate balance performance as a measure of neuromuscular control (Gorman et al., 2012; Miller et al., 2017). Due to the tasks involved in performing the Y-balance Test, it has recently been highlighted that it is not just a test of balance but also of other important components of neuromuscular control including range of motion, strength, stability and proprioception (DiStefano et al., 2018). While recognising the potential limitations of such tests as a pure balance measure, poor performance on the Star Excursion Balance Test has been shown to be associated with an increased risk of a variety of lower extremity injuries (Butler et al., 2013; Gribble et al., 2012; Plisky et al., 2006). Specifically, performance of the anterior reach (distance and asymmetry) has been shown to have the most consistent relationship with increased injury risk (Gonell et al., 2015; Smith et al., 2015).

Due to the possible improvements in neuromuscular control that come from exposing the body to a wide variety of movement patterns, it could be expected that multi-sport athletes would perform better in the Y-balance Test compared to single sport athletes (Gorman et al., 2012). This is supported by a recent study which showed that an increased asymmetry of the anterior reach portion of the Y-balance Test was associated with specialisation in female high school athletes (Miller et al., 2017). This is however one of the few studies is this area with further research needed to better explain the effects of single sport specialisation on Y-balance Test performance. Thus, the aim of this study was to examine the association between specialisation and neuromuscular performance, specifically performance on the Y-balance Test. A secondary aim was to examine the association between sport specialisation and overuse injury in adolescents in order to better inform sport participation guidelines in this population.

4.3 Methods

Secondary school students from five New Zealand secondary schools were invited to take part in this study during the 2019 and 2020 school years. Schools were selected based on a previous relationship with the physiotherapy clinics in which the primary researcher had worked. The included schools were a variety of sizes and based on the number of enrolled students in 2019 ranged from 301 to 1,280 students. All schools were in the high decile (measure of socioeconomic status) range of 8-10. Three of the schools included were privately funded and two were publicly funded. Ethical approval was

granted for this study by the AUT University Ethics Committee (AUTEC) (Appendix 4). All participants and their guardians provided assent/consent prior to participation.

4.3.1 Participants

Potential participants were recruited via an online survey system commonly used by schools. The students and their parents/guardians were provided with the study information and consent/assent forms (Appendix 1). Those participants that returned all relevant consent forms were then provided with an online weblink to complete a survey. To be included in the study, potential participants were in years 9-11 at high school and needed to be actively participating in some type of organised sporting activity.

4.3.2 Questionnaire

Participants were invited to complete an online survey via SurveyMonkey and Qualtrics. The survey consisted of 13 questions and was based on previous research by McGowan et al, (2020) which was used to examine specialisation and injury associations in NZ adolescents aged 10-13. The questionnaire is included in Appendix 6. Information was gathered about the age and gender of the participants. Participants were asked to report on all the organised sport they had participated in over the last 12 months, including the sport type, the season in which the sport was played, and the volume of sport performed each day. Furthermore, participants were asked to report on the average weekly volume of recreational free-play they participated in, including unstructured and unsupervised physical activity. Sport specialisation was then also determined using a previously used 3-point scale (Jayanthi et al., 2015). The scale included the following questions: (1) Can you choose one main sport that is more important than the others? (2) Do you train/compete more than 8 months out of the year in one sport? (3) Have you quite all other sports to focus on one sport? One point was given to each affirmative answer and the participant is then classified as low (score = 0-1), moderate (score = 2), or high (score = 3) specialisation. Acceptable reliability of this scoring system (ICC=0.85) has been reported in previous research (McGowan et al., 2020). Participants that were considered highly specialised on the three-point scale but reported participating in 2 hours of sport or less per week were re-allocated to the low specialisation group as the authors felt that participation in 2 hours of sport did not meet the commonly found definition of specialisation which involves year-round intensive training in a single sport at the exclusion of other sports (Jayanthi et al., 2015). Finally,

participants were asked about their history of injuries over the last 12 months, including details on location. Participants were excluded from the study if they were currently injured.

4.3.3 Injury Diagnosis

If the participant had reported an injury and sought physiotherapy assessment or treatment with one of two clinics associated with the primary researcher, clinical records including mechanism of injury were accessed to obtain an injury diagnosis. If the participant had sought treatment elsewhere or had not had the injury assessed, a phone interview between the participant and a qualified physiotherapist took place to determine a likely diagnosis. This was done in an attempt to reduce the effects of recall bias and to gain a greater understanding of the types of injuries being reported. Based on injury records or phone interviews injuries were classified as either acute or gradual-onset. Acute injuries were defined as being related to a single, traumatic event while gradual-onset injuries occurred without a specific sports-related event (Jayanthi et al., 2015; Jayanthi et al., 2018; Moseid et al., 2019; Pasulka et al., 2017). All injuries, including if a participant reported multiple separate injuries, were included in the analysis.

4.3.4 Balance Assessment

The Y-Balance Test was performed using a previously established standardised testing protocol that has been shown to be reliable (Plisky et al., 2006; Plisky et al., 2009). Firstly, the participants viewed a demonstration of the test followed by six trial attempts prior to testing (Linek, 2017). The participants performed the test barefoot to decrease the influence that footwear may have on balance. The participant started the test by standing on one foot on the stance plate with the most distal aspect of the toes at the starting line. The participant was asked to place their hands on their hips and to push the measurement box with the opposite leg in the anterior, posteromedial and posterolateral directions, with all tests being completed in this same order. The participants performed three trials on the left leg, followed by three trials on the right leg. Trials were repeated if the participant committed an error, including lifting the heel or toe, shifting weight onto the testing equipment or a loss of balance resulting in falling or stepping off the apparatus (see Appendix 2 for pictures demonstrating test positions).

Reach distance was measured from the most distal aspect of the toes of the stance foot, to the most distal aspect of the reach foot in the anterior, posteromedial and posterolateral directions. The greatest reach of three trials for each direction, for each leg, was used for data analysis. Reach distances were normalised to leg length, using the distance between the ASIS and the medial malleolus

in a supine position. A composite reach score was collected by taking the mean of the normalised reach scores. Reach symmetry was assessed by calculating the difference in absolute reach distance between the left and right sides for all three reach directions individually as well as the combined measure.

4.3.5 Statistical Analysis

All analyses were performed using the Statistical Programme for Social Sciences (SPSS) (IBM SPSS, Chicago), version 25. Categorical variables such as gender, specialisation level and injuries were summarised using frequencies and proportions (%). Continuous variables (e.g., sport volumes) were summarised using medians and interquartile range or means and standard deviations. A Kruskal-Wallis test was performed to examine difference in weekly hours of sport and free-play across specialisation groups.

In order to examine performance on the Y-balance test, the mean of the normalised reach scores for the left and right sides was taken to calculate a composite score for each of the three reach directions. Also, the composite reach scores for each direction were averaged to provide an overall performance measure for all directions. The examination of reach symmetry in all reach directions was used to compare left and right sides. Differences in Y-balance performance (reach symmetry and composite scores) between specialisation groups (low, moderate, high) were compared using one-way analysis of variance. An alpha level of $p<0.05$ was used to determine statistical significance.

4.4 Results

A total of 23 participants (10 female) with a mean age of 15.4 ± 0.8 years completed the questionnaire and were included in the study. Using the three-point classification method, 9 (39%) were classified as low specialisation, 9 (39%) moderate specialisation and 5 (22%) high specialisation. In terms of Y-balance performance there was no significant difference in any of the Y-balance measures between the specialisation groups (Refer to Table 6).

A summary of the weekly sport and free play hours is shown in Table 7. Although not statistically significant, the high specialisation group reported the highest organised sport hours (mean difference= 2.9 hours, $p=0.263$) and lowest free play hours (mean difference= 1.9 hours, $p=0.174$).

Table 6: Differences in Y-balance test performance between specialisation groups

	Specialisation Level			
	Low (mean ±SD)	**Moderate (mean** ±SD)	**High (mean** ±SD)	***p*-Value**
Anterior Composite (%LL)	66.9 ± 7.4	63.1 ± 4.1	63.8 ± 5.6	0.212
Postero-medial Composite (%LL)	103.7 ± 8.5	102.9 ± 9.9	98.8 ± 8.6	0.656
Postero-lateral Composite (%LL)	100.9 ± 7.4	100.6 ± 8.6	94.2 ± 10.2	0.404
Overall Composite (%LL)	100.6 ± 31.1	89.0 ± 6.9	85.0 ± 7.7	0.261
% Difference between left and right sides	4.3 ± 4.1	3.6 + 3.4	2.6 + 2.3	0.859

%LL – percentage of leg length. $p<0.05$ is statistically significant

Twenty-one participants reported at least one injury in the previous 12 months, 14 participants (61%) reported an acute injury, and 15 participants (65%) reported a gradual onset injury. A total of 36 (18 acute injuries and 18 gradual onset injuries) unique injuries were reported, of which 83% were to the lower limb, 11% to the upper limb 3% to the head and 3% to the torso. The most common injury sites included the knee/leg (n=10), the ankle (n=9) and the hip/thigh (n=7). Of the acute injuries, the most common confirmed diagnosis was a sprain to the lateral ankle (n=6) and for the gradual onset injuries, the most common confirmed diagnoses were patella-femoral pain (n=4) and Sever's disease (n=3). A total of 23 different sports were recorded across all participants, of which 13 were considered individual sports and 10 were team sports. The most common sports included football (n=9), netball (n=7) and touch rugby (n=6). The number of sports played per participants ranged from one to six.

A summary of proportions injured and injury counts per participant across the three specialisation groups is shown in Table 7. The median number of injuries per participant was similar across all specialisation groups. In addition, specialisation level did not appear to be associated with the proportion of players in each group reporting 'any injury'. However, based on confirmed diagnoses in each group, the proportion of players reporting gradual onset injuries was highest in the high

specialised group and this same group had the lowest proportion of players reporting acute injuries. A summary of injury diagnoses in each specialisation group is presented in Table 8.

Table 7: Summary of proportion injured and sport volumes in each specialisation group

Specialisation Level	Proportion reporting any injury	Proportion reporting acute injury	Proportion reporting gradual onset injury	Median number of injuries reported per participant (range)	Median weekly organised sport hours (range)	Median weekly recreational free-play hours (range)
Low (n=9)	78% (n=7)	56% (n=5)	44% (n=4)	1 (1-3)	5.3 (2-16.3)	4 (0-9)
Moderate (n=9)	100% (n=9)	89% (n=8)	67% (n=6)	2 (1-3)	7.5 (3.3-15.5)	5 (2-20)
High (n=5)	100% (n=5)	20% (n=1)	100% (n=5)	1 (1-3)	8.5 (5.5-17)	0.5 (0-15)

Table 8: Confirmed diagnoses of injuries in each specialisation group

	Low Specialisation	Moderate Specialisation	High Specialisation
Acute Injury	Lateral ankle sprain (n=2) Finger sprain Concussion Hamstring sprain	Fracture of hand Hamstring Strain (n=2) Adductor strain Lateral ankle sprain (n=3) Lower back muscular strain Rotator cuff sprain	MCL sprain
Gradual Onset Injury	Sever's disease Osgood Schlatter's disease Patello-femoral pain Medial tibial stress syndrome Rotator cuff tendinopathy	Sever's disease Osgood Schlatter's disease Patello-femoral pain (n=2) Rotator cuff tendinopathy Adductor tendinopathy	Sever's disease Adductor tendinopathy (n=2) Patello-femoral pain Medial tibial stress syndrome Peroneal tendinopathy

n=1 unless otherwise stated

4.5 Discussion

The primary aim of this study was to examine the association between specialisation and neuromuscular performance, specifically performance on the Y-balance Test. This study did not find an association between specialisation and Y-balance test performance. This result is similar to findings from a previous study, where no association was found between Y-Balance Test performance and specialisation in a group of American high school athletes with a mean age 15.7 ± 1.2 years (Gorman et al., 2012). However, these results are contrary to a study by Miller et al, (2017) where increased asymmetry of the anterior reach portion of the Y-balance Test was associated with higher levels of

specialisation in high school athletes. There are several possible explanations for this variation in results, one of which is to do with the specialisation classification method used in the various studies. Of the two previous studies that examined associations between specialisation and Y-balance performance, one study used solely a single-sport versus multi-sport model definition (Gorman et al., 2012). Miller et al, (2017) used various classification scales including two-point, three-point and six-point scales hence a large variation was seen in the results depending on which classification scale was used. In our study we chose to use the most commonly used three-point classification model as described by Jayanthi et al, (2015) which is one of the few rating methods shown to be reliable in previous research (McGowan et al., 2020).

A further explanation for variation in results regarding Y-balance performance is related to the sports included in the various studies. Of the previous two studies examining specialisation and Y-balance performance, one included a variety of sports and demonstrated no significant associations between test performance and specialisation (Gorman et al., 2012), whereas the other study limited the sports to basketball, volleyball, soccer and tennis and showed a significant association between specialisation and asymmetry of the anterior reach portion of the Y-balance Test (Miller et al., 2017). The current study did not limit the number of sports included and this resulted in a large variety of included sports (n=23). There is a possibility that balance performance could be sport-specific and affected by the specific movement or balance demands that are developed by participating in different sports. Furthermore, there is likely to be certain sports that would improve balance performance. For example, several of the highly specialised participants in the current study played netball, a sport which may have a greater impact on Y-balance performance due to the constraints of allowed steps while carrying the ball, meaning that athletes are frequently landing and balancing on one leg. Additionally, although specialisation has been linked to changes in movement development (DiStefano et al., 2018; Sugimoto et al., 2019), the Y-balance Test is a limited measure of neuromuscular control as it only examines a few components. While the primary focus is assessment of balance, there may be indirect assessment of strength, stability, range of motion and proprioception. A further limitation to the Y-balance test is that it does not assess the perceptual component of neuromuscular control. In sport, the ability for athletes to use information from the environment to support actions is based on an accurate and efficient relationship between perceptual and motor processes, known as perception-action coupling (Le Runigo et al., 2005). This may limit how valid the Y-balance test is for assessing neuromuscular control, however the test was selected due to its high reliability and ease of administration. Further research should focus on more sport-specific measures of neuromuscular control and including some sort of perceptual element would be beneficial.

The secondary aim of this study was to examine associations between specialisation and injury history. Although we did not analyse this formally due to the small sample size, the descriptive findings suggest that overall, in this group of NZ adolescents, there did not appear to be an association between specialisation category (low, moderate or high) and reporting a history of any injury. However, the highly specialised group did report the most gradual onset injuries and the least acute injuries. These findings are supported by previous research performed on a younger population of NZ youths aged 10-13 (McGowan et al., 2020). However, the results are contrary to findings from previous overseas research (Buckley et al., 2017; Jayanthi et al, 2018; McGuine et al., 2017). Despite there being no significant association between specialisation and weekly hours of sport or weekly hours of recreational free-play, there was an observable trend for increased weekly sport volume and decreased weekly free-play volume in the highly specialised group. This increase in weekly sport hours may be a possible explanation for the increased overuse injuries in the highly specialised group, as has been seen in previous research (Sugimoto et al., 2019). Clearly our findings need to be interpreted with caution as they are based on a very small sample and observations of simple descriptive statistics. In addition, due to this small sample size, confounding variables known to influence injury risk such as gender, age and weekly hours of sport volume were not considered in a formal analysis. Furthermore, although we were aware that maturation is a likely factor that has the potential to affect injury risk and neuromuscular control, we did not measure this during data collection. That said, this is one of the few studies where all injuries were confirmed by a physiotherapist which improves the validity of the injury data collected.

In relation to the types of injuries reported, the acute injuries were mostly soft tissue injuries such as ligament sprains or muscle strains, occurring most commonly in the lower limb. This finding is similar to recent statistics from the Accident Compensation Corporation (ACC) in New Zealand (2019) and also similar to findings in previous studies from overseas (Pakzad-Vaezi & Singhal, 2011; Shee et al., 2017). Regarding the reported gradual-onset injuries, the most common diagnoses were patella-femoral pain and tendinopathy/enthesopathy type injuries to the lower limb, such as Sever's disease or Osgood-Schlatter's disease. This finding is very similar to previous research in similar populations (Hall et al., 2015; McKay et al., 2016). These injuries are often considered to be related to the rapid period of growth that occurs in adolescence (Sanders et al., 2017), where epiphyseal growth plates in the long bones are growing very quickly. During this time in their development, adolescents are particularly susceptible to overuse type injuries (Hosseinzadeh & Milbrandt, 2011). Further research with an emphasis on high quality injury data is needed to examine the types of injuries being reported by adolescents in sport and to determine whether specialisation is a significant risk factor in this process.

In addition to the limitations related to sample size, this study was also limited by the cross-sectional study design, where we asked participants to recall events retrospectively. This allowed us to examine associations between variables, but we are unable to determine causation. With this type of study there is also likely an element of recall bias involved. In order to reduce this, we used a survey designed for younger participants and provided detailed instructions. As noted above a strength of this study was the quality of the injury data collected, where each injury diagnosis was confirmed either by clinical notes or via a phone interview with a qualified physiotherapist. This allowed us to determine whether injuries were considered acute or gradual onset and provided greater insight into the type of injuries being reported in this age group.

4.6 Conclusion

In this group of 12-16-year-old NZ adolescents there was no significant difference in Y-balance test performance between different groups based on level of sport specialisation. This study provided an exploratory investigation into this area but further, larger scale, prospective research is needed to examine the effects of sport specialisation on balance and other measures of neuromuscular control. Finally, growth-related and overuse injuries were common in this age group.

Chapter 5: Discussion and Conclusions

At the time in their lives when adolescents are developing and growing the most rapidly, it is important for the athlete and coaches to have well informed guidance around sport participation. Understanding the impact of sport specialisation on neuromuscular control and injury risk will help to optimise prevention strategies through improved sport participation guidelines for the adolescent population. Current sporting guidelines rely heavily on expert opinion, as there is limited evidence to support many of the recommendations (DiFiori et al., 2014). Thus, the aim of this thesis was to investigate the relationship between sport specialisation and injury in a secondary school population and to provide further evidence as to the potential benefits and downsides of single sport specialisation in adolescents.

The narrative review in Chapter 2 revealed some evidence that there is a positive association between specialisation and injury history in adolescent athletes (Bell et al., 2016; Buckley et al., 2017; Hall etal., 2015; Jayanthi et al., 2011; Jayanthi et al., 2015; Jayanthi et al., 2018; McGuine et al., 2017; Pasulka et al., 2017; Post et al., 2017; Post et al., 2017). However, this review also found significant variance in the strength of the associations found as a result of several methodological limitations. These included a lack of prospective study designs, as well as several variations in definitions of specialisation and injury. Furthermore, there was limited evidence of an association between specialisation and physical capability. Again, much variation was seen in the results, with some studies finding an association with their chosen physical outcome measure (DiStefano et al., 2018; Miller et al., 2017; Sugimoto et al., 2019) and others concluding there was no association (Beese, et al., 2015; Gorman et al., 2012).

Given the limited research available and the increases seen in both injuries and specialisation in adolescents, it was important to examine sport participation in two key settings in NZ. The first was high school sport, where the majority of active adolescent sport participation occurs and the second setting was a performance-based sports academy, a more recent phenomenon in adolescent sport and potentially a contributing factor to the high levels of sport specialisation seen in young athletes. Thus, the primary aim of Chapter 3 was to examine the association between specialisation level and injury history whilst the secondary aim was to investigate if participation in a performance-based academy was associated with differences in specialisation and/or sport participation. In this study of 12-16-year-old NZ adolescents (n=199), being highly specialised in one sport did not significantly increase the likelihood of reporting a history of injury. These findings were similar to previous research performed in NZ youth aged 10-13 (McGowan et al., 2020). However, our current findings did support an association between injury and increased sport volume that has also been seen in previous research

(McGowan et al., 2020; Sugimoto et al., 2019). The results of the study in Chapter 3 indicated that for every hour of additional sport volume, participants were 1.13 times more likely to report a time-loss injury. This result highlights the need for sport volume guidelines in adolescent sport. It is possible that specialisation pathways in adolescent sport are driving an increase in weekly sport volume. This increase in weekly hours of sport is often coupled with an increase in intensity, competition/training volume and repetition of similar movement patterns (Buckley et al., 2017). This combination of factors could in turn be what causes an increase in the risk of time-loss injury in adolescents.

One possible explanation for the link between sport specialisation suggests that adolescents who specialise may be denied the benefits of varied activity while facing additional physical, physiological, and psychological demands from intense training and competition (Pediatrics, 2000). Varied activity and movement patterns are thought to allow for optimal development of neuromuscular control, which includes stability, movement quality, strength, flexibility and balance. Having good neuromuscular control may have a protective effect for adolescents in sport and underdevelopment of one or more of the components of neuromuscular control may increase risk of injury (DiStefano et al., 2018). However, there is limited evidence in this area. Therefore, the aim of Chapter 4 was to examine the association between specialisation and neuromuscular performance, specifically performance on the Y-balance test. A secondary aim was to further contribute to the growing body of knowledge around the association between sport specialisation and overuse injury in adolescents with a particular focus on the quality of injury information collected (based on physiotherapy diagnosis rather than participant recall).

The findings from Chapter 4 did not show an association between specialisation and Y-balance test performance. The Y-balance Test is a derivative of the Star Excursion Balance Test and was chosen to evaluate balance performance as a measure of neuromuscular control as it has been shown in previous research to be reliable and valid (Robinson & Gribble, 2008). The results of the study were similar to findings from a previous study, where no association was found between Y-Balance test performance and specialisation in a group of American high school athletes (Gorman et al., 2012). However, these results are contrary to a study by (Miller et al., 2017) where increased asymmetry of the anterior reach portion of the Y-balance test was associated with higher levels of specialisation in high school athletes. There are several possible explanations for this variation in results, one of which is to do with the specialisation classification method used in the various studies and another is related to the sports included in the studies. There is a possibility that balance performance could be sport-specific and affected by the specific movement or balance demands that are developed by participating in different sports.

In addition, although we did not analyse this formally, the descriptive findings suggest that overall, in this small group of NZ adolescents, there did not appear to be an association between specialisation category (low, moderate or high) and reporting a history of any injury. However, the highly specialised group did report the most gradual onset injuries and the least acute injuries. One of the strengths of this study was the high-quality injury data, where diagnoses were confirmed by assessment from a qualified physiotherapist rather than relying on recall information from the participants. Regarding the reported gradual-onset injuries, the most common diagnoses were patella-femoral pain and tendinopathy/enthesopathy type injuries of the lower limb, such as Sever's disease or Osgood-Schlatter's disease. These injuries are similar to those reported as common in this age group previously and are thought to be related to rapid growth of epiphyseal growth plates in the long bones of adolescents (Hall et al., 2015; McKay et al., 2016).

5.1 Thesis Limitations

The studies presented in this thesis were at times limited by methodological constraints and these should be taken into account when interpreting the results. The study presented in Chapter 3 used a cross-sectional design that relied on recall of retrospective events. This allowed examination of associations between variables, but we were unable to determine causation. With this type of study there was also likely an element of recall bias. In order to reduce this, a survey that had been designed for younger participants was used and an information sheet was provided for the participant to read before commencing the survey.

Another limitation was that due to ethical considerations, the survey used in Chapter 3 was made completely anonymous. This meant that we were unable to collect potentially useful information such as date of birth to calculate exact chronological age and we were also unable to contact the participant following the survey to verify information given about injuries that they sustained over the past 12 months. Furthermore, due to ease of access, this research was performed in only two regions in NZ (Hawke's Bay and Kapiti) and the schools that were involved were all high decile, suggesting that these areas tended to be of higher socio-economic status. Therefore, the results may not be generalisable to the wider NZ population.

The findings regarding the association between specialisation and neuromuscular control presented in Chapter 4 need to be interpreted with caution as they are based on a small sample. Additionally, there was a large difference in the number of participants in the injured (n=21) and non-injured groups (n=2) in this study. This made formal analysis of the injury related data inappropriate. Due to the lack of formal analysis, confounding variables known to influence injury risk such as gender, age and weekly

hours of sport volume were not considered. That said, this is one of the few studies where all injuries were confirmed by a physiotherapist which improves the validity of the injury data collected.

Finally, this research was disrupted by the issues caused by Covid-19 lockdown in 2020. The data collection mainly occurred before this occurred, but it meant that any follow up or attempts to capture more participants were not possible and this impacted on the final sample size.

5.2 Recommendations for Future Research

Key areas for future research identified in the narrative literature review and subsequent chapters 3 and 4 include prospective, longitudinal studies following adolescents through their development in order to better understand the risk of injury in adolescents due to sport specialisation and the impact on neuromuscular development. This research should focus on using a standardised, three-point method of classifying specialisation level, as well as using injury data collection methods that avoid recall bias. This could be achieved by verifying injuries via clinical records or including assessment by a health professional. Additionally, further research is needed regarding performance-based academies for adolescents. Findings from Chapter 3 show that participation in these academies can certainly alter the volume of sport that adolescents are performing, and this warrants further investigation.

5.3 Conclusions

This thesis consists of two studies, the first examining the association between specialisation level and injury history and investigating if participation in a performance-based academy was associated with differences in specialisation and/or sport participation. The second study examined the association between specialisation and neuromuscular performance, specifically performance on the Y-balance test. Collectively, these studies suggest that specialisation is prevalent in the 12-16 adolescent age group, however it does not appear to increase the likelihood of reporting a history of sports injury nor does it result in worse balance performance. However, increased weekly sport volume does appear to increase the likelihood of reporting a history of time-loss injury. Additionally, sports specialisation levels are not increased in the performance-based academy setting, although involvement in an academy does increase sport participation hours and reduces recreational free-play hours. The results of this research may benefit the likes of coaches of secondary school or high-performance sport, health-care providers such as physiotherapists and of course, the adolescent athlete themselves. A better understanding of the impact of sport specialisation on neuromuscular

development and injury risk will help to optimise prevention strategies through improved sport participation guidelines for the adolescent population.

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Appendix 1: Consent Forms

Consent Form – Survey Section – Participants 16 years or older

Please tick the relevant boxes and fill in the information below. Either return to the sender or forward on to rhys@havelocknorthphysiotherapy.com

Project title: *Sport specialisation and lower limb overuse injury in adolescents.*

Project Supervisor: ***Dr Chris Whatman, Dr Duncan Reid and Jill Caldwell***

Researcher: ***Rhys Norton***

☐ I have read and understood the information provided about this research project in the Information Sheet dated 15th May 2019

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

☐ I understand that notes will be taken during the interviews

☐ If I have had an injury in the past 12 months and have had physiotherapy treatment at Havelock North Physiotherapy, I consent to my physiotherapy records being accessed and used for research purposes.

☐ If I have had an injury in the past 12 months but have not had treatment at Havelock North Physiotherapy, I agree to be contacted by a qualified physiotherapist to get more information on my injury

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

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

☐ I agree to take part in this research.

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

Participant's signature:

Participant's name:

Participant's Contact Details (if appropriate):

Phone :

Email :

Date:

Approved by the Auckland University of Technology Ethics Committee on 07/06/19 AUTEC Reference number 19/122

Consent Form – Balance Testing - Participants 16 years or older

Please tick the relevant boxes and fill in the information below. Either return to the sender or forward on to rhys@havelocknorthphysiotherapy.com

Project title:	*Sport specialisation and lower limb overuse injury in adolescents.*
Project Supervisor:	***Dr Chris Whatman, Prof Duncan Reid and Jill Caldwell***
Researcher:	***Rhys Norton***

☐ I have read and understood the information provided about this research project in the Information Sheet dated 15th May 2019.

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

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

☐ I understand that any information I give during this study will be confidential and my name will not be recorded on any collected data at any time

☐ I am currently injury-free and able to fully participate in balance testing

☐ I agree to take part in this research.

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

Participant's signature:

Participant's name:

Participant's Contact Details (if appropriate):

Date:

Approved by the Auckland University of Technology Ethics Committee on 07/06/19 AUTEC Reference number 19/122

Parent/Guardian Consent Form

Please tick the relevant boxes and fill in the information below. Either return to the sender or forward on to rhys@havelocknorthphysiotherapy.com

Project title: *Sport specialisation and lower limb overuse injury in adolescents.*

Project Supervisor: ***Dr Chris Whatman, Prof Duncan Reid and Jill Caldwell***

Researcher: ***Rhys Norton***

☐ I have read and understood the information provided about this research project in the Information Sheet dated 18th May 2020

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

☐ I understand that taking part in this study is voluntary (my choice) and that I may withdraw my child/children and/or myself from the study at any time without being disadvantaged in any way.

☐ If my child/children and/or I withdraw, I understand that all relevant information will be destroyed

☐ I understand that if I withdraw my child/children and/or myself from the study then I will be offered the choice between having any data that is identifiable as belonging to my child/children and/or myself removed or allowing it to continue to be used. However, once the findings have been produced, removal of our data may not be possible. I agree to my child/children taking part in this research.

☐ I agree to my child/children taking part in this research.

☐ I understand that my child is able to refuse to give assent to take part in this research.

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

Child/children's name/s :

Parent/Guardian's signature:

Parent/Guardian's name:

Parent/Guardian's Contact Details (if appropriate):

Date:

Approved by the Auckland University of Technology Ethics Committee on 07/06/19 AUTEC Reference number 19/122

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

Appendix 2: Information Sheets

Participant Information Sheet

Date Information Sheet Produced:

22/05/2019

Project Title

Sport Specialisation and overuse lower limb injuries in adolescents

An Invitation

Dear student,

My name is Rhys Norton, I'm a physio at Havelock North Physiotherapy and Masters student at Auckland University of Technology. I would like to invite you to be a part of my Masters research project that will look at how your sport participation might affect injury history. As a college student is years 9-11, I am interested in whether you are focusing on one sport or playing multiple sports and whether this might affect injuries. Today you are being invited to participate in the first part of the study which involves completion of an anonymous survey. This will give us some information on the injuries and sport participation of students your age. You are also being invited to participate in the second part of the study which involves looking at your history of injury and may involve having your balance assessed. If you agree to be participate in this second part of the study you will need to complete and return an assent form and your parents will need to complete a consent form.

What is the purpose of this research?

The purpose of this research is to help understand how your sport participation could affect injuries. You may gain some information about any possible injuries you have had. The information may help to guide your future sport participation and give you an idea of how research is done. The research will help me to gain a masters qualification and improve my knowledge on injuries in young people.

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

You are being invited as a local college student in years 9-11. You may be ruled out of the study if you currently have an injury or if you are currently in pain.

How do I agree to participate in this research?

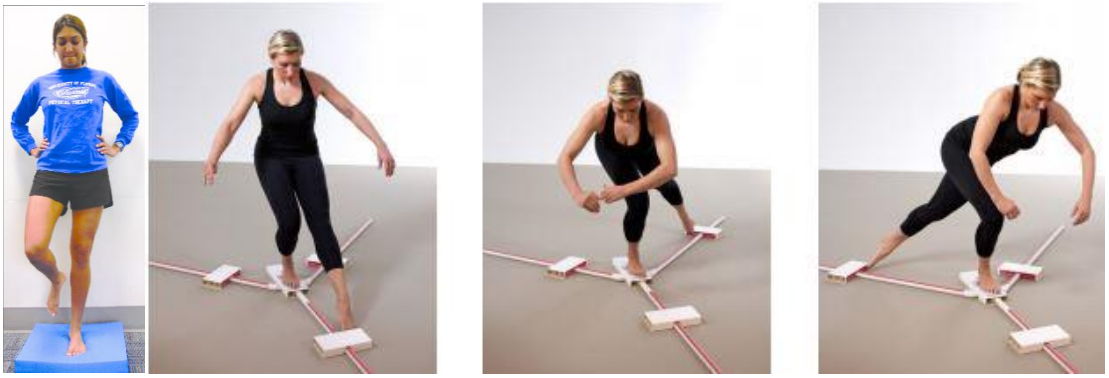
You can confirm your participation by completing the google docs including the second survey and assent form and returning it to school. You also need to get the parental consent form completed by your parent or caregiver. Please email the completed forms back to the sender or to rhys@havelocknorthphysiotherapy.com

Your participation in this research is voluntary (it is your choice) and whether or not you choose to participate will not advantage or disadvantage you. You can withdraw from the study at any time. If you choose to withdraw from the study, then you will be offered the choice between having any information about you to be removed or allowing it to continue to be used. However, once the study is finished and written up, it might not be possible to remove information.

What will happen in this research?

You will be asked about your sport and your history of injuries. If you have had any physiotherapy at Havelock North Physiotherapy, with your permission we will ask to look at your physio records to get more information about any injuries you have had. This will be done via the online physiotherapy notes program that we use. If any more information is needed, I will contact you to ask some more questions about your injuries. If you have not had physiotherapy at Havelock North Physiotherapy, I will contact you via phone to

try and work out a diagnosis for your injury. If needed you may be asked to come down to the clinic for a physiotherapy assessment. There will not be any cost involved in this assessment. Following this we will select a few students to participate in a balance test. Photos of the balance tests are shown below.



What are the discomforts and risks?

There should not be any kind of discomfort or embarrassment for you during the study. There is a very small risk you may fall when we are doing the balance test. A physiotherapist will be with you during this testing to make sure any injury is cared for.

What are the benefits?

Potential benefits for you:

- You will gain some understanding about how research is done
- You may gain some understanding about how your sport relates to your injury history
- You may get a better understanding of any injuries that haven't been yet assessed. If you have an injury that has not been treated by a physio, you will be able to get treatment if needed.

Possible benefit for the wider community:

- Might help to gain information about injuries in young people

Benefits for me:

- Will help to gain a masters qualification
- As a physiotherapist, I will gain understanding about injuries in young people and help me to treat them

What happens if I hurt myself?

If you hurt yourself during the testing and it qualifies, you will have access to ACC funding for treatment

How will my privacy be looked after?

The assent form, including your name, will be stored separately to the other information in a locked cabinet at AUT.

What are the costs of participating in this research?

The only cost involved for you will be your time. The survey should only take 5 minutes to complete, the balance assessment should take a further 10-15 minutes.

How long do I have to decide?

You have 2 weeks to decide if you wish to be a part of the study and return the forms to school.

Will I get to find out the results of this research?

If you are interested in the results of the research I will give information to your school which they will give to you.

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

If you have any worries about the study, please contact the Project Supervisor, Dr Chris Whatman, chris.whatman@aut.ac.nz, 09 921 9999 ext 7037

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

Who do I contact for further information about this research?

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

Researcher Contact Details:

Rhys Norton, rhys@havelocknorthphysiotherapy.com

Project Supervisor Contact Details:

Dr Chris Whatman, chris.whatman@aut.ac.nz, 09 921 9999 ext 7037

Approved by the Auckland University of Technology Ethics Committee on 07/06/19 AUTEC Reference number 19/122

Parent/Guardian Information Sheet

Date Information Sheet Produced:

22/05/2019

Project Title

Sport Specialisation and overuse lower limb injuries in adolescents

An Invitation

Dear parent or caregiver of potential participant,

My name is Rhys Norton, I'm a physiotherapist in Hawkes Bay and Masters student at Auckland University of Technology. I am an ex Paraparaumu College student and worked there for a few years as a physio. Your child is being invited to be a part of my Masters research project that is focused on looking at how their sport participation could relate to their injury history. As a college student is years 9-11 I am interested in whether your child is focusing on one sport or playing multiple sports and whether this has any relationship with their history of injuries. The study will initially involve an online survey, which will give us some information on the injuries and sport participation of students their age. There will be a second part to the study involving a balance test.

What is the purpose of this research?

The purpose of this research is to help gain an understanding of how sport participation could be associated with injury history. You and your child may gain some information about any possible injuries they have had. The information may help to guide future sport participation and give an idea of how research is done. The research will help me to gain a masters qualification and improve my knowledge on injuries in adolescents.

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

Your child is being invited as a local college student in years 9-11. They may be excluded from the study if they currently have an injury or are currently in pain.

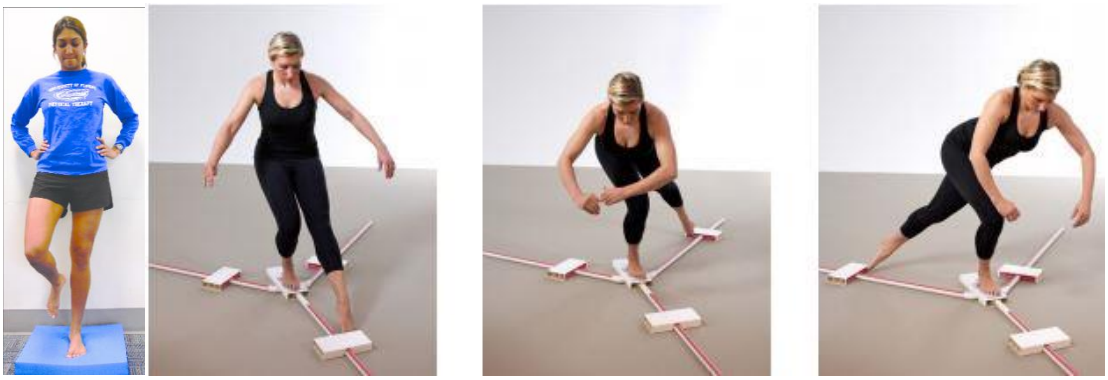
How do I agree to participate in this research?

You can confirm your participation by completing the online parental consent form. Your child will also need to complete their own consent form and survey that has been sent to their school email.

Your child's participation in this research is voluntary (it is a choice) and whether or not you choose to consent to your child participating will neither advantage nor disadvantage them. They are able to withdraw from the study at any time. If you or your child choose to withdraw from the study, then you will be offered the choice between having any data that is identifiable as belonging to them removed or allowing it to continue to be used. However, once the findings have been produced, removal of your data may not be possible.

What will happen in this research?

Your child will be asked about their sporting participation and history of injuries. With your permission, if they have had an injury and treatment at KCP we may ask to look at their physiotherapy records to get more information about any injuries. This will be done via the online physiotherapy clinical notes program that they use for patient records. If any additional information is needed, I will contact you or your child to ask some more questions about any injuries. If they have not had physiotherapy management, I may contact you or your child via phone to try and work out a diagnosis for their injury. If needed, you and your child may be asked to come down to the clinic for a physiotherapy assessment. There will be no cost involved in this assessment. Following this your child may be invited to participate in a balance test. Photos of the balance tests are shown below.



What are the discomforts and risks?

There should not be any kind of discomfort or embarrassment for the participants during the study. There is a very small risk they may fall when we are doing the balance test. A physiotherapist will be on site during this testing to ensure any injury is cared for.

What are the benefits?

Potential benefits for you:

- You will gain some understanding about how research is done
- You may gain some understanding about how your child's sport participation relates to their injury history
- You and your child may get a better understanding of any injuries that haven't been yet assessed. If they have an injury that has not been treated by a physiotherapist, they will have access to further physiotherapy management if required.

Possible benefit for the wider community:

- May help to guide sport participation and provide information on risk factors for injuries in adolescents

Benefits for me:

- Will help to gain a masters qualification
- As a physiotherapist, I will gain understanding of risk factors for injuries in adolescents and may provide treatment strategies to manage overuse injuries

What compensation is available for injury or negligence?

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

How will my privacy be protected?

The consent form, including your name and your child's name, will be stored separately to the other data in a locked cabinet at AUT. No personal information will be knowingly released to third parties.

What are the costs of participating in this research?

The only cost involved for the participant will be time. The survey should take 5 minutes to complete, the balance assessment should take a further 10-15 minutes.

What opportunity do I have to consider this invitation?

You have 2 weeks to consider and respond (accept or refuse) to the invitation and return the forms to school

Will I receive feedback on the results of this research?

If you are interested in the outcomes of the research I will provide summary to your school which they will distribute to you.

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

Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor, Dr Chris Whatman, chris.whatman@aut.ac.nz, 09 921 9999 ext 7037

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

Whom do I contact for further information about this research?

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

Researcher Contact Details:

Rhys Norton, rhys@havelocknorthphysiotherapy.com

Project Supervisor Contact Details:

Dr Chris Whatman, chris.whatman@aut.ac.nz, 09 921 9999 ext 7037

Approved by the Auckland University of Technology Ethics Committee on 07/06/19 AUTEC Reference number 19/122

Appendix 3: Questionnaire

Sport Participation and Injury Questionnaire

SPORT PARTICIPATION QUESTIONNAIRE

AUT

This questionnaire asks you to report on sports you play competitively and injuries you have sustained playing organised 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 Birth Year and Birth Month

3 What school do you go to?

4 What school year are you currently in?

Sport participation

The following questions relate to your organised sport activities over the **past 12 months**. This includes all organised competitions, games and training sessions.

5 Can you choose one main sport that is more important than the others?

- ☐ Yes
- ☐ No

6 Did you train/compete more than **8 months** out of the year in one main sport?

- ☐ Yes
- ☐ No

7 Have you only ever trained/competed in just one sport?

- ☐ Yes→ Go to Q **9**
- ☐ No → Go to Q **8**

8 Have you quit all other sports to focus on one main sport?

- ☐ Yes – At what age did you do this?
- ☐ No

9 During the **past 12 months**, what organised sport (practices and games) 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. Soccer game 1 hour "W"*
Sun	

10 Outside of school hours, on average, how many **hours per week** are you involved in non-organised exercise/ activity?
This refers to play, or physical activity that is just for fun. Eg Riding bikes, skateboarding, playing at the park, skiing for recreation, swimming at beach, surfing, playing on playgrounds

Hours/week

PTO

Injury history

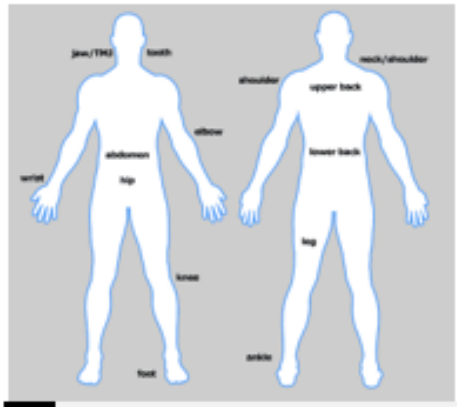
The following section asks about injuries that you have had from playing or training for your organised sport over the **past 12 months.**

11 Have you suffered from an injury that caused you to miss any practice, game or competition?

☐ Yes → Go to **12**

☐ No → Go to **13**

12 Please circle the area/s the injury occurred on the chart below.



13 Have you experienced any injuries while playing or practicing organised sport that you have continued to play or practice with?

☐ Yes → Mark on chart in Q **12**

☐ No → Thank-you for completing the survey.

Appendix 4: AUTEC Ethics Approval

15 July 2020

Chris Whatman
Faculty of Health and Environmental Sciences

Dear Chris

Re Ethics Application: **19/122 Sports specialisation and lower limb overuse injury in adolescents**

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 5 June 2022.

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: rnorton91@gmail.com; duncan.reid@aut.ac.nz; Jill Caldwell