Early Specialisation, Sport Participation Volume and Musculoskeletal Injury in Early Adolescent New Zealand Children

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Abstract

Introduction. Adolescent sport participation has changed in New Zealand (NZ) over recent years with increasing opportunities for young children to follow specialised, intensive and highly structured sport pathways. There have been anecdotal reports of a corresponding increase in injuries in 10–13-year-old NZ children, particularly gradual onset injuries. Overseas research suggests early specialisation and high participation volumes are associated with musculoskeletal injury, yet a recent systematic review highlighted the need for more research on this topic.

Aim. To investigate the degree of early specialisation and sport participation volumes of 10–13-year-old NZ children and examine the associations of these variables with injury history.

Methods. Children who attended the 2017 NZ Association of Intermediate and Middle Schools games were eligible to participate in this retrospective cross-sectional study. A survey was used to collect information regarding the degree of specialisation (high, moderate or low), sport participation volume, free-play volume and injuries sustained in the previous 12 months. Multiple logistic regression analyses were used to investigate the associations between each of specialisation and participation volume, and the likelihood of reporting a history of injury.

Results. Nine hundred and fourteen children (538 female; mean age [SD] 12.6±0.5) completed the questionnaire. The point prevalence of high specialisation was 25%. The median weekly sport participation volume was 4.4 hours (range 0.25–38 hours). Seventy-four percent of children reported a history of injury in the past 12 months (78% acute, 22% gradual onset). After adjusting for age, gender and participation volume, the odds of reporting an injury history for highly specialised children was not significantly higher than children with low specialisation (OR = 0.88; CI = 0.59–1.31; $p = 0.53$). Average weekly participation volume was associated with increased odds of reporting 'any injury' (OR = 1.07; CI = 1.02–1.12; $p < 0.01$) or 'gradual onset injury' (OR = 1.09; CI = 1.05–1.14; $p < 0.01$), even when adjusting for specialisation, age, school size and decile. Children participating in more hours of sport per week than age in years (OR = 2.42; CI = 1.27–4.62; $p = 0.02$), playing a single sport for more than 8 months of the year (OR = 1.60; CI = 1.07–2.36; $p = 0.02$), or exceeding a 2:1 ratio of organised to free-play hours per week (OR = 1.52; CI = 1.08–2.15; $p = 0.02$), had increased odds of reporting a 'gradual onset injury'.

Conclusion. Being highly specialised in one sport did not increase the odds of reporting a history of injury in this group of 10–13-year-old NZ children. This finding is contrary to overseas reports, perhaps due to differences in the age groups studied. Participating in higher weekly volumes of organised sport was associated with increased odds of reporting an injury or a gradual onset injury in the previous 12 months. The findings support previous recommendations to not participate in one sport for more than 8 months of the year, not participate in organised sport for more hours per week than years of age, and not exceed a 2:1 ratio of organised sport to free-play.

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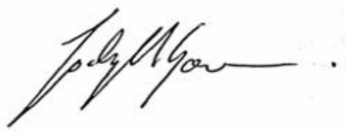
Attestation of Authorship

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

Student: Jody McGowan

Signature:



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Ethical Approval

The application for ethical approval was completed by Jody McGowan in May 2017 and submitted to AUTEC by Dr Chris Whatman (primary supervisor) on behalf of Jody McGowan on 25th May 2017. Ethical approval was granted on 26th June 2017, reference number 17/179 (see Appendix A).

Chapter 1: Introduction

1.1 Background

In the last 10 years there has been a notable increase in the number of New Zealand (NZ) children seeking assistance from physiotherapists and sport physicians to manage their sport-related injuries (Fulcher, 2015). Not only is there an increasing number, but the average age of these children seems to be reducing year to year, and the types of injuries they are presenting with are surprising (Personal communication, Robert Knight, Sport Physiotherapist). Anecdotally, many 10-, 11- and 12-year-olds have gradual onset pain from overuse, and many of the injuries are serious, at times requiring orthopaedic surgery. Sport-related injuries in these young adolescents are fast becoming a significant financial burden on NZ society, costing upwards of $28 million in 2016 (Accident Compensation Corporation, 2017). This clinically observed trend is not unique to NZ, and has resulted in many overseas media reports and studies investigating why this demographic of the population appear to be presenting more frequently with sport-related injuries (DiFiori et al., 2014; Klug & Flaum, 2014).

It is widely acknowledged that sport participation carries with it an inherent risk of injury (Caine & Purcell, 2016b). Both individual and team sport environments can give rise to injury through contact and non-contact situations. Of concern, is that a significant proportion of the sport-related injuries seen in 10–13-year-old children are unique to the anatomy of their rapidly growing bodies (McKay, Broderick, & Steinbeck, 2016). In healthy children, the peak period of skeletal growth occurs at approximately 11 years in girls and 13 years in boys (Sanders et al., 2017). During periods of rapid growth, children may be more vulnerable to sport-related musculoskeletal injuries than adults owing to their skeletal structure and the physiological mismatch between muscle strength and limb length (Caine & Purcell, 2016a).

There appears to be anecdotal evidence that many 10–13-year-old children are participating in highly intensive sporting schedules and that many of the injuries they present with could be treated simply with education, rest and activity modification (Launay, 2015). Unfortunately, there are reports of many barriers to this simple advice (Frisch, Croisier, Urhausen, Seil, & Theisen, 2009). Many children continue to participate intensively, despite ongoing pain. Some of the rationale given from children and parents includes concern about being dropped from squads, concern at potentially missing out on 'major' sporting events, and on occasion, pressure from coaches to continue playing despite injury (Whatman, Walters, & Schluter, 2018). There is a clear need for evidence-based sport participation and injury prevention guidelines for these young adolescents. Recent guidelines have been created from overseas research in the field of youth sport medicine, but these are not backed by research specific on the early adolescent child going through rapid musculoskeletal growth (Brenner et al., 2016; LaPrade et al., 2016; Lloyd et al., 2016). This thesis presents the findings from a New Zealand-specific study conducted with 10–13-year-old athletic children investigating associations between current sport practices and injury.

1.2 Statement of the Issues

1.2.2 Injuries are increasing in adolescent sport.

Overseas research indicates that sport-related injuries in adolescents have increased over the past 20 years, with one Canadian study indicating a 28% increase between 1992–2005 (Pakzad-Vaezi & Singhal, 2011), and another Australian study reporting an increase of 61% between 2003 and 2012 (Wong Shee, Clapperton, & Finch, 2017). In New Zealand, the Accident Compensation Corporation (ACC) are a government-funded organisation that offer financial assistance for treatment and compensation to all New Zealanders who sustain an accidental injury. Statistics from the five years between 2012 and 2017 demonstrate there has been a 26% increase in the number of sport-related musculoskeletal injuries in the 10–14-

year-old age group, and a 19% overall increase in <18-year-olds (Accident Compensation Corporation, 2017). However, this statistic likely only captures acute injuries that were registered by a health professional, and would not account for gradual onset and overuse injuries. Therefore, there remains a gap in the knowledge surrounding the total number of injuries sustained through sport in NZ. Overuse injury has been defined as a gradual onset of pain or dysfunction caused by sub-maximal repetitive loading of tissues (DiFiori et al., 2014; Luke et al., 2011). In an immature skeleton, there may be an intrinsic growth-related risk that makes bones and soft tissues, such as tendons and ligaments, particularly prone to injury (Zwick & Kocher, 2014). Specifically seen in young adolescents is the presence of epiphysial growth plates in long bones; these undergo rapid proliferation and growth during early adolescence, and are particularly susceptible to gradual onset injuries (Hosseinzadeh & Milbrandt, 2011; Jawetz, Shah, & Potter, 2015). Also, during puberty growth spurts, a young adolescent often experiences imbalances between the strength and length of limbs, leaving them vulnerable to both acute injury (sprains and strains) and overuse injury from poor motor control (Beese, Joy, Switzler, & Hicks-Little, 2015; Bowerman, Whatman, Harris, Bradshaw, & Karin, 2014; Feeley, Agel, & LaPrade, 2016). Overuse injuries can account for up to 53% of all adolescent sport-related injuries according to overseas data (Brenner, 2007), yet in NZ, there are no recent data giving any indication of how prevalent overuse injury is in adolescent sport.

1.2.3 Changes in adolescent sport practice.

Adolescent sport practice has changed over the last 20 years, both internationally and in New Zealand (Bergeron, 2010; Sam, 2007). There has been a trend towards more frequent, intensive and structured sport from an early age (Buckley et al., 2017), and this trend has been attributed to various sociological and economic factors (Mostafavifar, Best, & Myer, 2013; M. Smith, 2015). Legitimate sporting careers with lucrative financial rewards, sport scholarships and nationally driven pathways to elite performance have led to the quest for success being frequently sought from a young age (Jayanthi, Pinkham, Dugas, Patrick, & LaBella, 2013; Malina, 2010; Sugimoto, Stracciolini, Dawkins, Meehan, & Micheli, 2017). Many coaches, parents and adolescent athletes are subscribing to the idea that elite success comes from early exposure, intensive training and commitment to a chosen sport, something often referred to as early specialisation (Wilhelm, Choi, & Deitch, 2017). This pathway is commonly selected due to a theoretical rule, which states that 10,000 hours of deliberate practice is required to reach elite status. This 'rule' was popularised in the late 1990s in sport literature (Ford, Ward, Hodges, & Mark Williams, 2009) but was actually derived from research that looked at how many hours of deliberate practice elite violinists accumulated over their career compared to non-elite violinists (Ericsson, Krampe, & Tesch-Roemer, 1993). According to the original researcher, the results of that study are often misquoted in sport literature (Ericsson, 2013). In fact, the so called '10,000 hour rule' is a term Ericsson and colleagues never actually used (Ericsson, 2013). Despite this, the popularity of early sport specialisation as a pathway to elite success has resulted in significant changes in adolescent sport practice. These include: the evolution of early talent identification programmes; youth sport 'academies' in both schools and sport clubs; opportunities for young 'talented' children to join adult grade teams; and large regional representative tournaments for pre-adolescent ages (Rogers & Cassidy, 2015; Sam, 2007). All of these new opportunities in sport, have contributed to the notable increase in intensive, specialised sport practice by children in NZ (Sam, 2007; Walker & Haughey, 2012).

1.2.4 Early specialisation and intensive sport participation: risk versus benefit.

Sport specialisation has been defined as intensive participation in one sport, year round, at the exclusion of other sports (Jayanthi, Labella, Fischer, Pasulka, & Dugas, 2015), and early sport specialisation refers to this practice commencing before age 13 (LaPrade et al., 2016).

Intensive sport participation can refer to both a high intensity and high volumes of organised sport practice and/or competitions (Reider, 2017). Both sport specialisation and participation volume have been the focus of many recent adolescent sport medicine publications, with several authors suggesting these practices, either combined or in isolation, are risk factors for sustaining injuries, particularly overuse injuries (Brenner et al., 2016; Hall, Barber Foss, Hewett, & Myer, 2015; Jayanthi et al., 2015; McGuine et al., 2017; Post, Trigsted, et al., 2017). Other proposed negative consequences of early sport specialisation and excessive volume include psychological issues such as burnout, and societal issues such as social isolation, high rates of drop-out from sport, and associated physical inactivity (Brenner, 2007; Mostafavifar et al., 2013). However, early sport specialisation is a recognised sport development pathway that leads to some athletes achieving elite success (M. Smith, 2015). There have been many examples of world renowned athletes who have attributed their success to early, intensive, specialised practice, such as tennis stars Serena and Venus Williams and golfer Tiger Woods (Bailey, 2015; M. Smith, 2015). Some sports medicine practitioners argue that early exposure to well supervised skill practice may actually help refine and develop necessary skills for future success in a sport, and caution against discouragement of early specialisation (Fabricant et al., 2016; A. Smith et al., 2017). In contrast, some studies have demonstrated that elite athletes were more likely to succeed if they participated in a diverse range of sports during early-mid adolescence compared with participation in a single sport (Bridge & Toms, 2013; Buckley et al., 2017; Moesch, Elbe, Hauge, & Wikman, 2011; Wilhelm et al., 2017). This alternative to early specialisation is commonly referred to as early sampling, and these two pathways to potential athletic success, along with their probable outcomes, are summarised by Côté, Murphy-Mills, and Abernethy (2012) in their Developmental Model of Sport Participation (DMSP) (see Figure 1.1). This aside, elite success is a reality for only 0.2–0.5% of adolescent athletes (Mostafavifar et al., 2013), and therefore, the argument to support early specialisation pathways for the masses of children may lose its strength when weighed up in light of the potential increased injury risk and negative psychosocial implications (Côté et al., 2012).

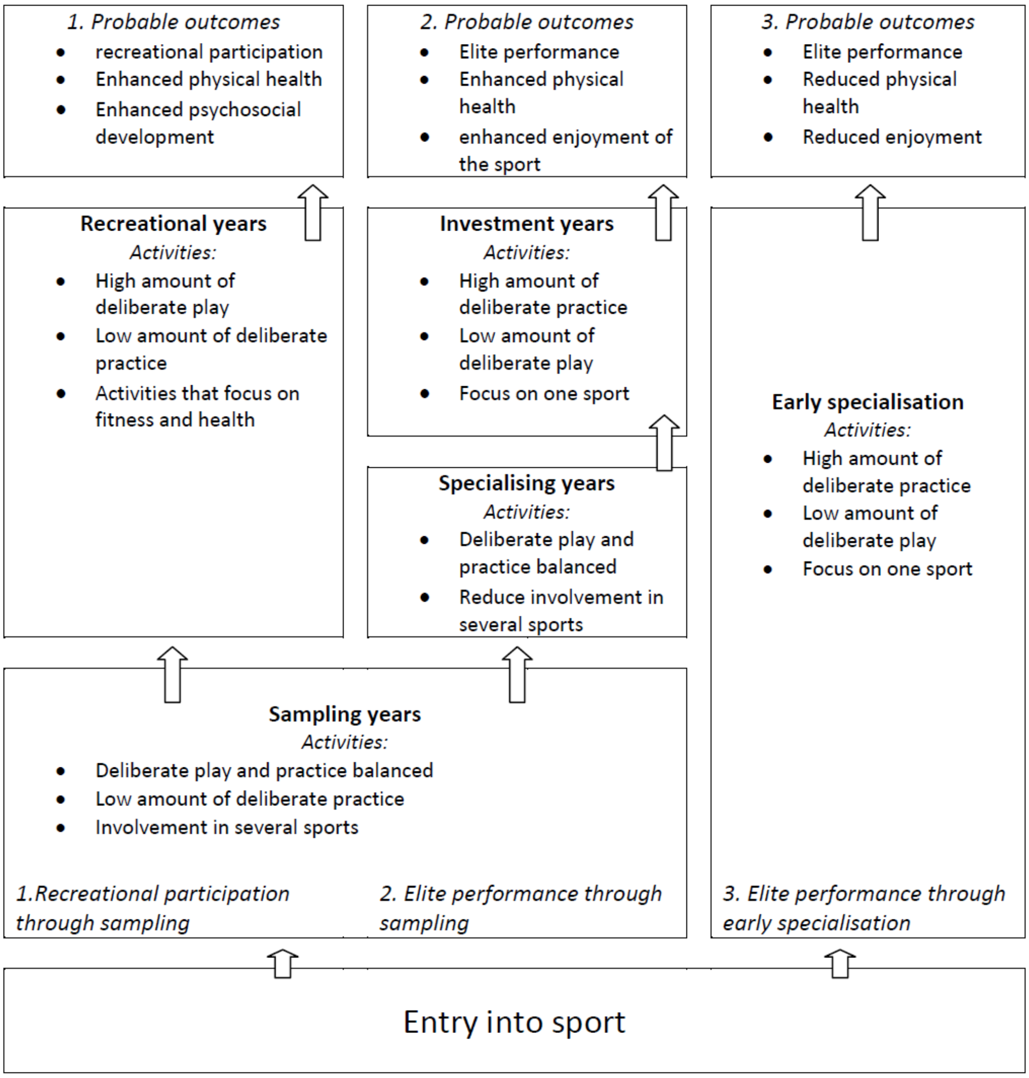

Figure 1.1 The Developmental Model of Sport Participation. Adapted from Côté et al. (2012).

The question that remains heavily debated in the literature is at what age is it appropriate to support sport specialisation? Cote's DMSP suggests it is reasonable to offer specialisation in a sport after age 13 years, with age 16 years being appropriate for an athlete to commence a highly specialised pathway (Côté et al., 2012). In a consensus statement published by the

American Orthopaedic Society for Sports Medicine (AOSSM), early sport specialisation was defined by specific criteria, one of which was the involvement of pre-pubertal (defined as roughly age 12 years, or 7th grade at school) children (LaPrade et al., 2016). Yet, despite these age ranges, many studies that have looked at specialisation and its association with injury (Jayanthi, Dechert, & Durazo, 2011; Post, Thein-Nissenbaum, et al., 2017) have not specifically looked at the 10–13-year age group. Conclusions regarding the association between specialisation and injury have been drawn from cohorts of athletes spanning ages 8–18 years (Cuff, Loud, & O'Riordan, 2010; Jayanthi et al., 2015; McGuine et al., 2017; Post, Bell, et al., 2017; Post, Trigsted, et al., 2017). No previous study has investigated the effects of early specialisation and intensive participation on a specifically targeted early adolescent age range. Thus, there is a clear lack of evidence to inform coaches, parents and athletes as to when, or if, sports specialisation is appropriate.

1.2.5 Current position statements on injury prevention in adolescent sport.

Published guidelines for adolescent injury prevention state that specialisation in a single sport should be avoided until late adolescence due to the increased risk of 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, 2016). Other specific volume-based recommendations include close monitoring for overuse injury in children who participate in: (i) more hours of organised sport per week than their chronological age; (ii) one sport for more than 8 months of the year; and (iii) more than 16 hours per week in total (LaPrade et al., 2016). Many of these recommendations are made with cautions and provisos stating that the evidence supporting these recommendations remains scarce. It is a big responsibility for sport medicine clinicians dealing with the injured adolescent athlete to ensure recommendations being made surrounding specialisation and participation volumes are backed by sound research. Whilst reducing injuries may be the primary health focus, the importance of promoting sport participation for life and aiding the athlete to achieve sporting goals must not be forgotten (A. Smith et al., 2017).

1.3 Aim and Research Questions

1.3.1 Aim.

The aim of this research is to investigate adolescent sport practice in NZ in terms of specialisation and participation volume during early adolescence and the association of these variables with injury.

1.3.2 Research questions.

1. What is the degree of specialisation within a group of 10–13 year old NZ athletes attending a large organised sports event?

2. Is there an association between the degree of specialisation and sport related musculoskeletal injury history, specifically gradual onset injury within this group?

3. What is the organised sport participation volume of this group of 10–13 year old NZ athletes?

4. Is there an association between participation volume and injury history, specifically overuse injury?

5. Do certain sports demonstrate higher rates of specialisation, weekly participation volumes or injury frequency?

1.4 Thesis Structure

The thesis is presented in the traditional pathway one format. Chapters are organised under the following headings: introduction, literature review, methods, results, discussion and conclusion. All references are provided at the end of the document.

Chapter 2: Literature Review

Introduction

The purpose of this chapter is provide a narrative review critiquing the academic literature investigating early sport specialisation and the volume of organised sport participation by adolescents in relation to musculoskeletal injury. This chapter is divided into three sections. Section 1 contains a review of the literature on specialisation. This section will critique the methods used to rate specialisation, the prevalence of specialisation in adolescent sport, and the association of early specialisation with any sports injury, and specifically, with gradual onset injury.

Section 2 contains a review of the literature that investigates the association between the volume of organised sport participation by adolescents and musculoskeletal injury. The different ways of recording volume exposure in adolescent sport research will be presented, followed by a summary of the volume-based recommendations being promoted in current injury prevention guidelines. The association between the volume of organised sport participation and any musculoskeletal injury will be critiqued, as will the association between exceeding the current volume recommendations and sustaining a gradual onset injury.

Section 3 will report on the injury definitions that were used in the studies identified in the two previous sections (specialisation and participation volume) and critique the discrepancies in defining an injury in adolescent sport research.

2.1 Specialisation in Adolescent Sport

A literature search was conducted in July 2017 using the electronic databases subscribed to by the Auckland University of Technology, including MEDLINE, SPORT Discus and CINAHL plus via EBSCO health and SCOPUS. Search terms that were used included injur*

OR overuse OR pain*, youth OR young OR adolescen* OR immatur* OR pediatric OR paediatric, sport OR athlet* OR activ*, specialis* OR specializ*. The search was limited to English language studies published in peer reviewed journals between 2000–2017. A total of 256 articles were identified from this search. To be included in the review, the studies had to be original research papers with a focus on sport specialisation in adolescents (defined as 19 years of age or under (World Health Organisation, 2013)) and its association with musculoskeletal injury. Studies were excluded if they were expert opinion, critical commentary or review articles. All abstracts were screened, and using the inclusion and exclusion criteria, eight studies were selected for this review. A further three studies were identified from the reference lists of included studies, resulting in 11 studies being included.

Of the 11 studies identified, three were prospective cohort studies, two were retrospective cohort studies, three were clinical case–control studies, and three were cross-sectional studies. A summary of the key characteristics of the included papers is presented in Table 2.1. All included studies were published between 2010 and 2017 highlighting that, while the concept of early sport specialisation is not new, research looking specifically at the association between specialisation and injury is a recent trend. There were 13,689 participants across the 11 studies with the mean number of participants being 1,245. The largest study included 3,276 participants and the smallest study included 302 participants, with a mean age of 14.8 years (based on the eight studies that reported mean ages) and an age range of 7–19 years. Of the 11 studies included, all but two found an association between specialisation and injury. Seven of the 11 studies differentiated between overuse and acute injuries, with five of these studies demonstrating an association between specialisation and overuse injury. The definitions and methods of rating specialisation varied between the studies.

Table 2.1

Overview of specialisation studies

Study	**Study design**	**Participants**	**Sport**	**Outcomes**	**Association results**
Cuff, Loud & O'Riordan, 2010	Retrospective cohort study	*N* =3276 (45% female) American high school athletes. Median age 16 years (range 14-19)	Any	*Specialisation:* *n* = 1271 students played same sport all year (37.3%) *Injury:* *n* = 1685 total injuries. *n* = 949 acute *n* = 584 overuse *n* = 152 unknown classification of injury	Playing sports year round without taking a break showed 42% increased risk of reporting an overuse injury.
Jayanthi, Dechert & Durazo, 2011	Prospective cohort study	*N* = 519 (53% female) Elite junior tennis players Mean age 13.5 years (range 10–18 years)	Tennis	*Specialisation:* 69.6% reported playing and competing in only tennis. *Injury:* 31.4% of players reported a prior injury related to tennis in the past year (retrospective data) *n* = 29 medical withdrawals recorded over the four-week study period.	Significant relationship (OR: 1.55; $p < 0.05$) between players who reported a history of a tennis-related injury or illness in the past year and those who only played tennis (specialised). No significant association between specialisation and future medical withdrawal risk.

Study	Study design	Participants	Sport	Outcomes	Association results
Hall et al., 2015	Retrospective cohort study	*N* = 546 (all female) American high school athletes Average age for specialised group 14.5 years and multi-sport group 13.8 years.	Basketball Soccer Volleyball	*Specialisation:* *n* = 189 single sport specialised athletes *Injury:* *n* = 153 (28%) had anterior knee pain at examination.	Single sport athletes reported a 1.5-fold greater incidence of anterior knee pain and a 4-fold greater risk of developing overuse aphophysitis.
Jayanthi et al., 2015	Case–control study	*N* = 1190 (50.3% female) American athletes attending sports medical clinics. Mean age 13.7 ± 2.3 (range 7–18 years)	Any	*Specialisation:* High = 28.1%; Mod = 33.7%; Low = 38.2% *Injury:* *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 serious overuse injury (OR: 1.36; $p < 0.01$) among young athletes who specialised in one sport, independent of training volume and age.
Bell et al., 2016	Cross-sectional study	*N* = 302 (60% females) American high school athletes Mean age 15.6 years (range 13–18 years)	Soccer Basketball Tennis Volleyball (female only)	*Specialisation:* a) three-point classification. High = 36.4%; Mod = 34.8%; Low = 34.8% b) Self classification method Multi-sport = 70.5%; Single-sport = 29.5% *Injury:* *n* = 64 history of knee injury; *n* = 33 history of hip injury; *n* = 33 history of overuse knee injury	Athletes who were highly specialised were significantly more likely ($p = 0.048$) to report a history of overuse knee injuries than moderate or low specialised athletes (association based on three-point scale only).

Study	Study design	Participants	Sport	Outcomes	Association results
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	*Specialisation:* *n* = 237 (49%) reported the age they dropped all other sport to focus on main sport, and therefore were considered specialised. *Injury:* 80.8% reported sustaining an injury (note 123 surveys returned were excluded for not answering the injury section).	Single sport specialisation was NOT significantly associated with a higher reported injury history (did not distinguish between acute or overuse injury).
Jayanthi, 2017	Conference abstract (Ongoing prospective cohort study)	*N* = 1083 (gender not specified) American athletes attending a sports medicine clinic Mean age not stated. Age range 7–18 yrs.	Any	*Specialisation:* Not available in current publication format, but higher proportion of injured subjects were highly specialised. *Injury:* 427 reported an injury (39.4%).	Injured follow up subjects were more likely to be female ($p < 0.02$) and report age of specialization <12 ($p = 0.03$).
Pasulka et al., 2017	Case–control study	*N* = 1190 (50.3% female) American athletes attending medical clinics Mean age 13.7 ± 2.3 years (range 7–18 years old)	Any	*Specialisation:* 26% **single** sport specialised. *Injury:* *n* = 242 injuries in **single sport** specialised group (73% overuse or serious overuse).	Single sport specialized athletes who participated in individual sports had significantly higher odds (OR: 1.67; p = 0.037) of reporting an overuse or serious overuse injury but significantly lower odds (OR 0.37; $p = 0.001$) of reporting an acute injury than the single sport specialised athletes playing team sports.

Study	Study design	Participants	Sport	Outcomes	Association results
Post, Bell et al., 2017	Cross-sectional study	*N*=1544 (50.5% female) American high school athletes Mean age 16.1 ± 1.1 years	Any	*Specialisation:* High = 13.4%; Mod = 27.1%, Low = 59.5%. *Injury:* *N* = 487 (31.5%) reported a previous lower extremity injury. (Not differentiated between acute or overuse).	High level of specialisation associated with significantly higher odds (OR: 2.58; p = 0.001) of reporting a history of a previous lower extremity injury when adjusted for gender.
Post, Trigsted et al., 2017	Case–control study	*N* = 2011 (49% female) American athletes Mean age 13.7 ± 1.6 years (range 12–18 years)	Any	*Specialisation:* High = 37.5%; Mod = 37.3%; Low = 25.2% *Injury:* *n* = 992 history of injury (any type) *n* = 377 history of overuse injury.	Athletes who were highly specialised were significantly more likely to report a history or any injury (OR 1.59; $p < 0.001$) or a history of gradual onset injury (OR 1.45; $p = 0.01$) when compared to athletes who rated low specialisation.
McGuine et al., 2017	Prospective cohort study	*N* = 1544 (50.5% female) American high school athletes Mean age 16.1 ± 1.1 years	Any	*Specialisation:* High = 13%; Mod = 27%; Low = 60% *Injury:* *n* = 276 lower extremity injuries recorded over the 2015/2016 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 who rated low specialisation. Highly specialised athletes were significantly more likely to sustain a gradual or recurrent injury (HR 4.74; $p < 0.001$) than athletes in the low specialisation group.

OR: Odds ratio, HR: Hazard ratio, Mod=moderate

2.1.1 Measuring and rating specialisation.

The majority of studies used a three-point rating system to categorise athletes as low, medium or highly specialised (Bell et al., 2016; Jayanthi, 2017; Jayanthi et al., 2015; McGuine et al., 2017; Pasulka, Jayanthi, McCann, Dugas, & LaBella, 2017; Post, Bell, et al., 2017; Post, Trigsted, et al., 2017). This system was first reported by Jayanthi et al. (2015) and was based on their definition of specialisation from their earlier review, which defined sport specialisation as "intense, year-round training in a single sport with the exclusion of other sports" (Jayanthi et al., 2013, p. 252). Using this definition, the authors developed three questions to categorise the athletes into specialisation groups. The three questions were 1. "Can you pick a main sport?"; 2. "Did you quit other sports to focus on a main sport?"; and 3. Do you train for more than 8 months in a year?". For every positive response, the athlete was given a point, giving a total score range of 0–3. A score of 3 was considered high specialisation, a score of 2 was considered moderate specialisation, and a score ≤1 was considered low specialisation. Subsequent studies have used this system to classify their participants into specialisation groups. Some variations to the questions have been proposed, and limitations have been reported. For example, athletes who have only ever played one sport were potentially being wrongly categorised as only moderately specialised given they would answer "no" to question two (Pasulka et al., 2017). To date, there are no published validity or reliability studies for this rating system.

Other studies have used simplified methods to define and rate their participants' level of specialisation. Specialisation has been identified based on whether or not participants consider themselves single or multi-sport athletes (Hall et al., 2015), or simply if they report playing one sport year-round versus multiple sports year-round (Cuff et al., 2010). A further method asked the age at which the athlete withdrew from all other sports to focus on one main sport, and used this to categorise the athletes as specialised or not (Kahlenberg, Nair, Monroe, Terry, & Edwards, 2016). Finally, a tennis-specific study reported athletes to be specialised if they only played and competed in tennis in the last year (Jayanthi et al., 2011). While these simplified methods are easily understood, a recent study comparing the three-point scale to a single versus multi-sport classification, suggested the three-point scale more accurately identified specialisation in adolescent athletes (Bell et al., 2016). The lack of a single validated, reliable and standardised measure to rate specialisation in children makes it challenging to make direct comparisons of research results investigating this variable.

2.1.2 Specialisation prevalence in adolescent sport.

The average percentage of highly specialised or single sport specialised athletes across the included studies was 34.5% (range 13.4%–69.9%). Females had a higher prevalence of high specialisation (16.4%) than males (10.4%) in one cross-sectional study (Post, Bell, et al., 2017). This was supported by another clinical case–control study that reported only 37.7% of the single sport specialised athletes in their cohort to be male (Pasulka et al., 2017), and to a lesser degree by another case–control study in which 46.2% of the highly specialised athletes were male (Post, Trigsted, et al., 2017). Two other studies demonstrated no significant differences in the percentages of each gender among highly specialised athletes (Bell et al., 2016; Post, Thein-Nissenbaum, et al., 2017).

School size attended was shown to be associated with the degree of specialisation. Adolescent athletes from smaller schools (<500 students) were more likely to be categorised as low specialisation or multi-sport athletes than were adolescent athletes of a similar age who attended large (>1000 students) schools (Bell et al., 2016; Post, Bell, et al., 2017).

In several studies, a trend was noted that showed as age increased, the degree of specialisation increased (Jayanthi et al., 2011; Post, Thein-Nissenbaum, et al., 2017), whereas other studies noted peaks in specialisation prevalence at 15 years of age, with a drop after age

16 years (Bell et al., 2016; Post, Trigsted, et al., 2017). Another study demonstrated a significant difference in the mean age of their highly specialised athlete group compared with their low specialised athlete group, with those that were highly specialised being an average of 1 year older (Jayanthi et al., 2015).

The average age when athletes became highly specialised differed amongst sports, with gymnastics and tennis athletes specialising young (age 8-10 years) (Jayanthi et al., 2011; Pasulka et al., 2017) and American football and baseball athletes specialising later (age 13-14 years) (Pasulka et al., 2017). When grouping sports as either individual or team sports, individual sport athletes specialised younger (11.2 years), and had a higher prevalence of high specialisation (44.8%) on the three-point scale when compared with team sport athletes (12 years; 31.3%) (Pasulka et al., 2017).

2.1.3 Association of early specialisation with injury.

There is some evidence of a positive association between the degree of sport specialisation and musculoskeletal injury in adolescent athletes (Bell et al., 2016; Hall et al., 2015; Jayanthi, 2017; Jayanthi et al., 2011; Jayanthi et al., 2015; McGuine et al., 2017; Pasulka et al., 2017; Post, Bell, et al., 2017; Post, Trigsted, et al., 2017). However, the strength of the association is variable and influenced by common methodological faults in the studies, as well as by the range of definitions used to define both injury and specialisation. In a study on 540 elite level junior tennis players, 69.6% were classified as specialised (Jayanthi et al., 2011). Retrospective data on injuries revealed a significant association between reporting a tennis related injury or illness in the past 12 months and specialisation (OR 1.55; $p<0.05$). However, prospective data gathered over a four-week peak summer tournament period showed no independent relationship between specialisation and medical withdrawals from matches. The definition used for medical withdrawals in this study was "an injury or illness that prevents the player from playing in current and subsequent tournaments". This definition is very restrictive, and likely to significantly under-report injuries. Furthermore, the authors were unable to confirm the reasons for each medical withdrawal by the athletes, leaving it unclear as to how many, or what type of injuries occurred during the four-week period. A stronger association between adolescent sport specialisation and a history of injury was demonstrated by several large case-control studies (Jayanthi et al., 2015; Pasulka et al., 2017; Post, Trigsted, et al., 2017). In the first of these three studies, 822 adolescent athletes who attended one of two sport medicine clinics due to an injury (cases) were compared with 368 uninjured adolescent athletes attending medical practices for wellness checks (controls). Analysis of the data showed that athletes who specialised in a single sport, independent of age or time spent participating, had higher odds of reporting an injury (OR 1.27; 95% CI, 1.07–1.52). This association was strongest in the highly specialised athletes, with the highest odds for association with any injury (OR 1.58; 95% CI, 1.11–2.24), an overuse injury (OR 1.50; 95% CI, 1.01–2.22), or a serious overuse injury (OR 2.25; 95% CI 1.27–3.99). However, no significant association was demonstrated between high specialisation and acute injuries. From a methodological perspective, this study did have several limitations. In particular, there are threats to both the external and internal validity based on the recruitment of participants being non-representative of all adolescent athletes. The control group was also considerably smaller and not age-matched to the study group; therefore, this was not a true case–control study.

In another case–controlled study of 2011 athletes from Wisconsin, USA (12–18 years of age), highly specialised athletes were more likely to report a history of either acute or overuse injury than athletes categorised as low specialisation (Post, Trigsted, et al., 2017). Because the participants of this study were recruited from various summer sport tournaments, competitions and practices, the data are likely to be more representative of the entire adolescent athlete population. This addresses one of the methodological limitations of the study by Jayanthi et al. (2015). The main difference between the results from the Post, Trigsted, et al. (2017) study and those from the Jayanthi et al. (2015) study was in the association between high specialisation and the type of injuries. While Jayanthi et al. (2015) showed no significant association between high specialisation and acute injury, Post, Trigsted, et al. (2017) demonstrated an association between high specialisation and a history of acute injury (OR 1.58; 95% CI 1.24–2.00). This may be due to the populations studied. The injured participants in the Jayanthi et al. (2015) study came from sports medicine departments, which are likely to over-represent overuse injuries. The authors explained that acute injuries in their State were more likely to present to an emergency department than a sports medicine clinic. However, other studies on non-clinical populations have demonstrated associations between high specialisation and a history of overuse injury, but have failed to show significant associations between high specialisation and acute injury history (Bell et al., 2016; Hall et al., 2015). This suggests that other characteristics of the participants in the Post, Trigsted, et al. (2017) study may be responsible for the acute injury association. There were significantly more athletes who specialised in team sports compared with individual sports, suggesting that contact or collision in team sports could be a separate risk factor for acute injury. Previous epidemiological studies have demonstrated that overall injury incidence is higher in team sports than individual sports (Stracciolini, Casciano, Levey Friedman, Meehan Iii, & Micheli, 2015; Theisen et al., 2013); however, the use of a time-loss definition for injury in these studies may have led to overuse injuries being under reported, and therefore skewing the data (Clarsen, Myklebust, & Bahr, 2013). This idea that there may be differences between highly specialised individual sport athletes and highly specialised team sport athletes in regards to injury patterns was investigated recently, in a large case–control study of 1190 participants (Pasulka et al., 2017). Overall, highly specialised individual sport athletes reported a higher percentage of overuse injuries than team sport athletes. Conversely, highly specialised team sport athletes reported a higher percentage of acute injuries than individual sport athletes. In common with other retrospective studies, there are methodological limitations affecting the strength of these results, such as recall bias. However, in summary, highly specialised athletes competing in team sports may present a higher overall injury risk, and it has been demonstrated that there is a stronger association between specialisation and acute injury in team sport athletes.

At the time of this review, only one prospective study seeking to confirm the association between specialisation and injury had been published (McGuine et al., 2017). In a cohort of 1544 athletes followed over the 2015–2016 school year, a significant association was demonstrated between high specialisation and lower extremity injury (LEI). Using the three-point scale to categorise specialisation, the authors demonstrated that the incidence of LEI over the school year for both moderate and highly specialised athletes, was significantly higher than the incidence of LEI in athletes rated as having low specialisation, even after controlling for other potential risk factors, such as gender, competition volume, a previous history of LEI, and age. A further prospective study by a well-known researcher in this field may support this finding once completed and published (Jayanthi, 2017). At a sports medicine conference in Monaco in March 2017, preliminary data were presented from this ongoing prospective study. Three years of six-monthly follow-up on more than 1000 athletes who presented to a sports physician with either an injury or for a routine medical suggested that a higher proportion of highly specialised athletes recorded an injury compared to athletes categorised as low specialisation. These prospective cohort studies add strength to the developing trend found in the retrospective literature that suggests a high degree of specialisation is associated with either a higher history or rate of injuries in adolescent athletes.

Only two studies reported that single sport specialisation was not significantly associated with a higher reported history of injury in adolescent athletes (Cuff et al., 2010; Kahlenberg et al., 2016). In the retrospective study by Cuff et al. (2010), 3,276 athletes were surveyed about sports played in the previous 12 months, broken into four seasons, as well as about any injuries sustained during this period. The primary aim of their study was to analyse the association between seasonal participation in sport and overuse injuries. While the authors did not specifically identify specialisation as a variable, they did group athletes who played sport year-round as same-sport or different-sport athletes. Based on the definition of specialisation in the literature (Jayanthi et al., 2015), this would accurately identify a subset of athletes considered to be specialised. The results from this study did not show any significant difference in regards to overuse injury between single-sport and multi-sport athletes, who participated in organised sport year round. They did, however, show that it was significantly more likely that athletes who played sport in all four seasons would report an overuse injury (OR 1.42; 95% CI 1.05–1.92) compared with athletes who played sport in less than four seasons. This suggests that the risk factor for overuse injury was related to playing year-round, rather than specialisation in a single sport. Obvious limitations include the retrospective design and the reliance on self-reporting, which the authors acknowledged but did not attempt to address by face-to-face interview or validation of their study tool. The response rate was only 44%; however, the large number of participants analysed strengthens this study's results.

The only other study that concluded that there was no association between specialisation and injury was the cross-sectional study by Kahlenberg et al. (2016). This study was based on an online survey distributed to parents of high school athletes from a single school in a major metropolitan city in the USA. Various potential risk factors for injury were analysed against the number of total reported injuries, including playing only one sport. There was no significant difference in the number of reported injuries in athletes who played one sport compared with those who played more than one sport. The authors concluded from their study that a higher total number of hours of sport participation as well as contact sport participation were significantly associated with a higher history of injury, but playing a single sport was not. It is worth mentioning that this study had a rather low response rate (27.6%), and defined sport specialisation by categorising athletes by single- versus multi-sport participation. This simple specialisation definition was unable to detect a significant association with injury history in a previous study, whereas the three-point scale categorising specialisation applied to the same cohort of participants was able to demonstrate a significant association between injury history and high specialisation (Bell et al., 2016). This finding alone may threaten the validity of the findings from the Kahlenberg et al. (2016) study.

2.1.4 Association of specialisation with overuse injury.

Several studies have looked specifically into the type of injury adolescent athletes are reporting and have attempted to analyse the association between sport specialisation and overuse injury. There is some evidence that a higher degree of specialisation is related specifically to overuse injury (Bell et al., 2016; Hall et al., 2015; Jayanthi et al., 2015; McGuine et al., 2017). Athletes who reported a serious overuse injury (defined as an injury requiring >1 month rest from sport) were almost twice as likely to be highly specialised compared with athletes who reported less serious overuse injuries (Jayanthi et al., 2015). Adolescent females playing basketball, volleyball or soccer who were considered more specialised (played a single sport) were 50% more likely to report patellofemoral pain than females who played multiple sports (Hall et al., 2015). Likewise a history of overuse knee injury was reported in a group of highly specialised high school athletes (male and female) playing soccer, basketball, tennis or volleyball (Bell et al., 2016). Based on retrospective data, specific growth-related overuse problems (apophysitis) such as Sinding-Larsen

Johansson syndrome and Osgood Schlatters disease were four times more likely to occur in female single-sport athletes compared with female multi-sport athletes (Hall et al., 2015). Furthermore, unspecified gradual onset injuries (likely consistent with an overuse definition) were more prevalent in highly specialised high school athletes who specialised in a variety of sports, compared with athletes categorised as low specialisation (McGuine et al., 2017).

Some research indicates the association of specialisation with overuse injury may also be dependent on the nature of the sport and training patterns. In a large retrospective cohort study, highly specialised individual sport athletes had significantly greater rates of overuse injury history than highly specialised athletes who played team sports (Pasulka et al., 2017). Furthermore, playing the same sport in all four seasons of the year (highly specialised), be it team or individual based, without taking a break, significantly increased the odds of sustaining an overuse injury when compared with having at least one season's rest (Cuff et al., 2010). However, as there was no significant difference in overuse injury rate between those that played the same sport in all four seasons versus those that played a variety of sports spanning all four seasons, it was not necessarily specialisation in one sport that led to the increased risk of overuse injury. Instead, it was the continuous participation in sport, without a break, that increased the risk.

2.1.5 Section summary.

Specialisation is an emerging trend in adolescent sports and is best categorised by using a continuous scale (Bell et al., 2016). The three-point scale commonly used is yet to be validated or tested for reliability. Specialisation prevalence varies depending on the size of the school the athlete attends, the nature of the sport (team versus individual) and possibly may be influenced by gender and age. Although the number of studies is limited, there is an emerging body of evidence that supports an association between sport specialisation and musculoskeletal injury in adolescent athletes across age ranges spanning 7–18 years.

However, the overall quality of the evidence is reduced by study design (specifically a lack of prospective studies that can establish cause and effect), recall bias and the lack of validated and reliable measures. Also, the lack of homogeneity between the studies' definitions, and methods used to collect data, for both injury and specialisation, make it difficult to compare outcomes. The association of single-sport specialisation with overuse injury is more consistently reported than that with acute injury, although the nature of the sport and the patterns of training may be more of a significant influence in this association. To establish if and when adolescent sport specialisation is safe, further research should look at the association between early specialisation and injury in specific cohorts of athletes who meet the current definition of early adolescence (approx. 10–14 years, (Sawyer, Azzopardi, Wickremarathne, & Patton, 2018)).

2.2 Volume of Organised Sport Participation by Adolescents

A separate literature search to identify literature relevant to volume of participation in adolescent sport was conducted in July 2017 using the electronic databases subscribed to by Auckland University of Technology. These included MEDLINE, SPORTDiscus and CINAHL plus via EBSCO health and SCOPUS. Search terms included: risk OR "risk factor*", injur* OR overuse OR pain*, youth OR pediatric* OR child* OR paediatric* OR young OR immatur* OR adolescen*, sport* OR athlet*, "training volume" OR volume OR participation OR "training pattern*". The search was limited to studies that had been published in English and in peer-reviewed journals. Studies were included in the review if the mean age of the participants was <19 years, they were original research publications, they reported organised sport participation volume (described in terms of participation time or sport exposures), and they analysed the association of participation volume with injury rates. Expert opinions, critical reviews and critical commentary publications were excluded.

Nineteen studies identified from the literature search met the criteria for inclusion. A summary of the main findings of each study can be found in Table 2.2. Of the 19 studies identified, 10 were prospective cohort studies, three were retrospective cohort studies, three were case–control studies and three were cross-sectional studies. Collectively there were 15,989 participants over the 19 studies (range 46–3,739). The average age of participants across the studies was 15 years. Of the 19 studies included, 11 found some association between organised sport participation volume and injury. The magnitude of the association between participation volume and injury varied considerably across the studies, and the overall outcomes were influenced by the injury definitions, the data recording methods and the various exposure definitions. Whilst 10 of the studies identified for this review had prospective designs (53%), six of these were confined to one sport; therefore, generalising the findings of these single-sport studies to athlete populations in other sports should be done with caution. Eleven of the studies differentiated between acute and gradual onset/overuse injuries in their analysis, with only five of these demonstrating a specific association between volume and overuse injury.

2.2.1 Organised sport participation volume measurements.

Organised sport participation volume was measured and reported differently across many of the studies. Most commonly, volume was recorded as total time exposed to organised sport (training and competitions) per week, ranging from 3.5 to 19.8 hours per week over 13 studies (see studies numbered 1–13 in Table 2.2). Other ways to report organised sport participation volume included: the number of training sessions and competitions per 100 days (average 94.7 per athlete) (Theisen et al., 2013); tennis match exposures per athlete (average seven over four weeks) (Jayanthi et al., 2011); number of primary sport competitions (not training sessions) in the past 12 months (17.2% had >60) (Post, Bell, et al., 2017); average sport participations (training and competitions) per week (1.7 per athlete) (Junge, Runge, Juul-Kristensen, & Wedderkopp, 2016); number of sports seasons defined as the total number of sports played in each of four seasons over a year (median of four per athlete) (Cuff et al., 2010); and number of pitches per year in a baseball study (2,563 per injured athlete) (Olsen, Fleisig, Dun, Loftice, & Andrews, 2006). In addition to weekly participation volume, four studies reported participation volume in terms of the number of months per year participants played sport, which on average was 10.1 (range 7.9–12.0) (Cuff et al., 2010; Jayanthi et al., 2015; Olsen et al., 2006; Post, Trigsted, et al., 2017).

Table 2.2

Summary of studies investigating participation volume in adolescent sports.

Study#	Author	Design	Participants	Sport	Organised sport volume	Injuries	Association results
1.	**Visnes & Bahr (2013)**	Prospective cohort study (study period of four years)	*N* = 141 (51% female) Mean age 16.8 ± 0.8 years (range 16–18 yrs) Elite volleyball players from a school in Norway.	Volleyball	Average total training volume (hours/week) of two groups: Developed jumpers knee = 19.8 ± 3.4 Did not develop jumpers knee =16.8 ± 4.4	*n* = 28 athletes (20%) developed jumpers knee over 4-year study period (6 female)	The jumper's knee group had higher total sport participation volume compared with those who remained asymptomatic ($p = 0.01$)
2.	**Malisoux et al (2013)**	Prospective cohort study (study period 41 weeks)	*N* = 154 (35.1% female) Mean age 14.1 years (range 12–19) Athletes from a regional sport school in Luxemburg.	Any (grouped as team, racket or individual sports)	Mean weekly volume (in minutes per week) -Team 536 ± 120 -Racket 788 ± 465 -Individual 667 ± 177	*n* = 181 injuries recorded. *n* = 42 overuse injuries.	No statistically significant associations were found between training frequency, volume or intensity and injury risk.

Study#	Author	Design	Participants	Sport	Organised sport volume	Injuries	Association results
3.	**von Rosen et al (2016)**	Prospective cohort study (study period 26 weeks)	*N* = 64 (52% female) Mean age 17 ± 1 years (Range 16–18) Swedish elite high school orienteering athletes.	Orienteering	Average training hours/week = 6.8 Average competition time in hours/week/ athlete =0.4 Average overall participation volume per week =7.2 hours	*n* = 109 (18 injuries per 1000 hours of participation) (22% acute, 78% overuse injuries)	Higher training volume resulted in a longer time to first injury ($p = 0.001$)
4.	**Purnell et al. (2010)**	Retrospective cohort study	*N* = 73 (95% female) Mean age 13.4 ± 3.6 years (range 8–26) Recreational or competitive athletes from NSW, Australia	Acrobatic gymnastics	Mean training volume hrs/week (by age grouping) ≤12 years (*n* = 25) = 6.6 ≥13 years (*n* = 48) = 11.2	*n* = 195 total injuries (lifetime) Not specified if overuse or acute. 2.94 injuries/1000 hours of training	Specific training thresholds existed in the 11–13-year-old groups, and when exceeded, demonstrated a statistically significant increased risk for injury. >8 hours /week at age 11 ($p < 0.01$) >8.5 hours/week at age 12 ($p = 0.04$) >8.5 hours/week at age 13 ($p = 0.05$) >9.75 hours/week at age 14 ($p = 0$ .08) >12.75 hours/week at age 15 ($p = 0.07$)

Study#	Author	Design	Participants	Sport	Organised sport volume	Injuries	Association results
5.	**Post, Trigsted, et al. (2017)**	Case–control study	*N* = 2011 (49% female) Mean age = 13.7 ± 1.6 years (range 12–18) Athletes from summer tournaments, competitions and practices in Wisconsin, USA.	Any	Mean volume of sport participation (hours/week) Injured group=16 ± 6.7 Non-injured group=14.5 ± 6.9 Median number months/year playing main sport Injured group = 10 (IQR7–12) Non-injured group = 9 (IQR 6–12)	*n* = 992 (49%) of participants reported being injured over the previous 12 months *n* = 377 (19%) of participants reported an overuse injury over past 12 months.	Athletes who participated in more organised sport hours/week than their age in years were significantly more likely to report a history of any injury compared with athletes who did not exceed (OR 1.34; 95% CI, 1.12–1.6; $p < 0.001$). Athletes who competed in a main sport for >8 months of the year were significantly more likely to report any injury (OR 1.85; 95% CI [1.50–2.27] $p < 0.001$) or an overuse injury (OR 1.60; 95% CI [1.21–2.14] P < 0.01) than those who do not exceed this threshold. No significant difference in injury between exceeding 2:1 organised to free-play participation and not exceeding
6.	**Kahlenberg et al. (2016)**	Cross-sectional study	*N* = 484 (42% female) Mean age 15.9 years (range 13–21) High school athletes from a major city in USA.	Any	Mean hours of participation in sport/year = 504.3±71.6 (converted to hours/week = 9.69)	Mean total of lifetime injuries sustained per athlete was 1.7±1.3. (Not specified if acute or overuse)	Higher volume of participation associated with higher number of reported lifetime injuries (OR 1.001; 95% CI, 1.00–1.00; $p = 0.03$).

Study#	Author	Design	Participants	Sport	Organised sport volume	Injuries	Association results
7.	**Jayanthi et al. (2015)**	Case–control study	*N* = 1190 (49.3% female) Mean age 13.7 ± 2.3 years (range 7–18) Recruited from sport medicine clinics OR from paediatric/ family practice in Chicago, USA.	Any	Mean hours organised sports per week = 10.6 ± 6.2 Mean months per year spent training for sports = 8.6 ± 3.5	*n* = 846 unique injuries (32.6% acute; 67.4% overuse) 23.5% of the overuse injuries were considered serious (at least 1 month's rest from sport)	Injured athletes reported significantly more organised sport (11.2 hrs/week) than uninjured athletes (9.1 hrs/week); $p < 0.01$ Athletes with serious overuse injuries had 2 times the odds of competing in more hours per week of organised sport than their age in years when compared to athletes without serious overuse injury (95% CI, 1.35–2.95; $p < 0.001$) Athletes with serious overuse injury were 1.7 times more likely to exceed a 2:1 ratio of organised sport to free-play compared with athletes without serious overuse injury (95% CI, 1.12–2.56; $p < 0.01$)
8.	**Boström et al. (2016)**	Cross-sectional study	*N* = 3739 (46% female) Age range 11–15 years. Swedish athletes registered in a summer sports camp.	Football Ice hockey Handball Floorball Tennis Basketball Gymnastics	32% trained ≤5–6 hrs/week 30% trained 7–8 hours/week 37% trained ≥9–10 hrs/week	*N* = 1273 total injuries reported	While there was a linear trend with injuries increasing in relation to higher training hours, the total time training was not significantly associated with injuries when adjusted for confounders (gender and age)

Study#	Author	Design	Participants	Sport	Organised sport volume	Injuries	Association results
9.	**Hjelm et al. (2012)**	Prospective cohort study (two-year study period)	*N* = 55 (36% female) Mean age 15.5 ± 3.17 Junior elite tennis players from a Swedish tennis club.	Tennis	Mean hours/year of play (practice and competitions) Injured group = 446 ± 331.7 (converted 8.58 hrs/week) Uninjured group = 246 ± 119.4 (converted 4.73 hrs/week)	*n* = 100 total injuries (55% overuse). Injury incidence 1.5 injuries/1000 hours of playing exposure.	Injured players performed significantly more singles play per week (p = 0.0001) and played significantly more tennis hours per year (p = 0.016) than the uninjured players.
10.	**Rejeb et al. (2017)**	Prospective cohort study (followed over a period of one to five years)	*N* = 166 (all male) Age 12–18 years From a middle eastern sports programme	Table tennis Fencing Gymnastics Squash Swimming Golf Shooting Track and field	Average training volume per athlete = 8 sessions per week, 120 minutes per session, total 16 hrs/week.	*n* = 643 injuries (50.3% overuse injuries) Injury incidence 5.5/1000 hrs exposure.	Training volume exposure was significantly associated with a risk of injury (RR 1.01; $p < 0.001$) and with overuse injury (RR 1.03; $p < 0.001$).
11.	**Gianoudis et al. (2008)**	Prospective cohort study (pilot) (15-week study period)	*N* = 46 (39% female) Mean age 16 years (range 14.7–18.1) Basketball players from specialist sports school in Melbourne, Australia.	Basketball	Mean physical activity per athlete = 10.1 ± 3.3 hours/week Basketball specific activity per athlete = 7.7 hours/week Basketball activity included training (58.5%), competition (16%), refereeing (11.6%), shooting practice (10.1%) and recreational basketball (3.9%)	*n* = 35 injuries. (62.9% acute and 37.1% overuse) Incidence rate of injuries over the season was 0.76 per athlete.	No significant differences were found in the total amount of physical activity undertaken weekly by injured (10.31 hours) and uninjured (9.87 hours) athletes (p = 0.67). The injured athletes performed significantly more hours of basketball refereeing (1.21 vs. 0.54 hours p = 0.04), shooting practice (0.97 vs. 0.56 hours p = 0.09) and recreational basketball (0.46 vs. 0.12 hours p = 0.06) each week when compared with uninjured athletes.

Study#	Author	Design	Participants	Sport	Organised sport volume	Injuries	Association results
12.	**Huxley et al. (2014)**	Retrospective cohort study	*N* = 103 (64% female) Mean age 17.7 ± 2.4 years. NSW Institute of Sport emerging talent squad in track and field athletics.	Track and field	Mean weekly training hours per age group: 13–14 yrs = 5.69 ± 2.53 15–16 yrs = 7.30 ± 2.20 >17 yrs = 13.37 ± 5.72	*n* = 200 injuries (76% overuse)	No significant difference in training hours between injured and uninjured athletes in any age group for either any injury or overuse injury. Injured athletes in the 13–14 year (p = 0.009) and 15–16 year (p = 0.009) groups reported significantly higher self-reported training intensities than non-injured athletes.
13.	**Møller et al. (2017)**	Prospective cohort study (study period = 31 weeks)	*N* = 679 (44% female) Age range 14–18 years	Handball	108.31 total playing hours per athlete over season (31 weeks) Converted = 3.49 hours/week/athlete.	*n* = 106 new shoulder injuries (51% overuse) 1.4 shoulder injuries/1000 participation hours.	Injury rate was greatest among players who increased their handball load by more than 60% compared with those who decreased or increased <20% (HR 1.91; 95% CI, 1.00–3.70; p = 0.05)
14.	**Junge et al. (2016)**	Longitudinal prospective cohort study (three-year period spanning spring 2011–summer 2014)	*N* = 1326 (51.5% female) Median ages (range 8–15 years) (each study year); 2011 = 10; 2012 = 11; 2013 = 12 Public schools in Denmark.	Any	Average 1.7 sport participations (not expressed in specific times due to different sports having different times for each training or competition) per participant, per week over the study years.	*n* = 2127 lower extremity injuries. *n* = 806 knee injuries (85% overuse)	No significant association between number of sport participations and traumatic (OR 1.02; 95% CI 0.87–1.21; P = 0.746) or overuse (OR 0.96; 95% CI 0.89–1.04; P = 0.368) knee injuries over all sports. Sport specific associations observed.

Study#	Author	Design	Participants	Sport	Organised sport volume	Injuries	Association results
15.	**Theisen et al. (2013)**	Prospective cohort study (study period one school year)	*N* = 279 (44% female) (Team sport athletes *n* = 137; Individual sport athletes *n* = 142) Age range 12–19 yrs Sports school in Luxemburg.	Any	Average number of light (LT) and intense (IT) trainings and competitions (C) per 100 days per athlete. **Team sports** C = 15.21 ± 6.74; IT = 18.38 ± 17.71; LT = 61.15 ± 25.25 **Individual sports** C = 7.57 ± 5.91; IT = 28.49 ± 22.26; LT = 58.77 ± 22.87	*n* = 483 (28% overuse injuries) Injury incidence /1000 hrs of exposure = 4.3 (Team sports = 6.1; Individual sports = 2.88)	In team sports only, the number of competitions per 100 days was associated with increased injury risk (HR = 1.072; 95% CI, 1.033–1.11; $p<0.001$).
16.	**Olsen et al. (2006)**	Case–control study	Group one (case) All males who had undergone shoulder or elbow surgery *n* = 95; Mean age 18.6 ± 1.6. Group two (control) non-injured males *n* = 45; Mean age 18.3 yrs ± 1.5	Baseball pitchers	Number of pitches per year per athlete in injured group = 2562.7 ± 1505.7 Number of pitches per year per athlete in control group=1268.9 ± 1039.7 Months per year of competitive pitching; Injured = 7.9 ± 2.5; Control = 5.5 ± 2.3.	Injuries needing surgical intervention = 95 *n* = 66 elbow surgery *n* = 29 shoulder surgery	The injured group pitched significantly more months during the year (7.9 vs. 5.5), games per year (28.8 vs. 18.6), innings per game (5.6 vs. 4.3), pitches per game (87.8 vs. 66.2), pitches per year (2562.7 vs. 1268.9) than the uninjured group ($p < 0.001$).

Study#	Author	Design	Participants	Sport	Organised sport volume	Injuries	Association results
17.	**Jayanthi et al. (2011)**	Prospective cohort study (4-week study period)	*N* = 519 (53.5% female) mean age 13.5 years (range 10–18) Elite junior tennis players	Tennis	Mean matches/ athlete over study period = 6.97 Mean number of tournaments/athlete over study period = 1.81	29 medical withdrawals during the study period (incidence 8.6 per 1000 match exposures)	No significant relationship between weekly practice volume and competing >9 months of the year and risk of medical withdrawal ($p = 0.26$).
18.	**Post, Bell, et al. (2017)**	Cross-sectional design	*N* = 1544 (50.5% female) Mean age 16.1 ± 1.1 years High school athletes from Wisconsin, USA.	Any	Categorised by number of primary sport competitions within the past 12 months. Low <30 *n* = 816 (52.8%) Moderate 30–60 *n* = 463 (30%) High >60 *n* = 265 (17.2%)	*N* = 599 lower extremity injuries (not differentiated into acute and overuse)	Athletes with high (OR 2.08; 95% CI, 1.55–2.80; $p < 0.001$) or moderate (OR 1.68; 95% CI, 1.31–2.16; $p < 0.001$) primary competition volume were significantly more likely to report a lower extremity injury in the past year.
19.	**Cuff et al. (2010)**	Retrospective cohort study	*N* = 3276 (45% female) Median age 16 years (range 14–19) High school athletes from Ohio, USA.	Any	"total sport seasons" defined as a sum of the number of all sports played over the 4 seasons = median 4 (range 1–24)	*n* = 2353 total injuries (29% overuse)	Playing sport (same or different) in all 4 seasons was associated with sustaining an overuse injury (OR 1.42; 95% CI, 1.05–1.92) when compared with playing sport in 3 or fewer seasons a year.

OR=odds ratio, HR =hazard ratio, NSW= New South Wales, CI= confidence interval, RR= risk ratio

2.2.2 Adolescent sport participation volume recommendations.

To be able to effectively advise athletes on injury prevention, clinicians need evidence-based guidelines regarding the recommended volume thresholds for safe participation in adolescent sport. Several well-known sport medicine bodies, such as the American Orthopaedic Society for Sports Medicine (LaPrade et al., 2016), the National Athletic Trainers' Association (McLeod et al., 2011), the American Medical Society for Sports Medicine (DiFiori et al., 2014), and the American Academy of Pediatrics (Brenner et al., 2016) have published position statements and/or guidelines for clinicians to use as a part of their education and injury prevention messages. The volume-specific recommendations that have been promoted in these statements vary and include: not participating in more organised sport hours per week than the athlete’s chronological age (Brenner et al., 2016; LaPrade et al., 2016); not playing any one sport for more than 8 months of the year (Brenner et al., 2016; DiFiori et al., 2014; McLeod et al., 2011); not exceeding a 2:1 ratio of organised sport hours to free-play activity hours per week (Brenner et al., 2016); and not exceeding 16 hours per week of organised sport (LaPrade et al., 2016; McLeod et al., 2011). All of these authors noted the scarcity of research backing these volume-based recommendations.

2.2.3 Association between volume of sport and sport-related injury.

An association between organised sport participation volume by adolescent athletes and an increased risk of injury, or a history of injury was reported in 11 of the included studies (58%). As identified above, the way in which volume was measured differs between the studies. The following section will look at the various associations between sport volume and injury based on the measure of volume used in the study.

Weekly hours of organised sport.

The association between how many hours an adolescent participates in organised sport per week and injury was analysed by the majority of the included studies (n=13; 68%) (see studies 1–13 Table 2.2), with six of the 13 studies concluding that as weekly organised sport volume increased so did the odds of sustaining an injury or reporting a history of injury (see Table 2.2). Within these studies, the magnitude of the association varied considerably, and the level of association in two studies in particular was particularly weak. In one of these, a cross-sectional study, the mean weekly hours per athlete of 9.69 per week was calculated from a yearly total sport participation of 504.3 hours per athlete (Kahlenberg et al., 2016). In this study, the reported association of yearly participation hours with the number of lifetime injuries sustained per athlete, although significant (p = 0.003), was very small in magnitude (OR 1.001; 95% CI, 1.00–1.001). Using a more meaningful measure of hours would help the interpretation of these types of results and provide a better way for sport medicine clinicians to advise their patients. A 10% change in odds is often considered to be the minimum practically significant value, and in this example, by using simple calculations, we can say an athlete would have to increase their yearly hours by more than 100 (approx. 2 more hours per week, every week) to reach this marker. Similarly, in another prospective study of all male athletes (Rejeb et al., 2017), the significant (p < 0.001) yet small increased risk (0.3%) of sustaining an overuse injury for every additional participation hour per season is practically not very useful nor meaningful to young athletes. In this study, a season was defined as 46 weeks, so if an athlete increased their sport participation volume by 1 hour per week, there would be a 13.8% increased risk of injury for the season. This number gives a far better understanding of how the relative risk relates to athletic practice.

One volume guideline that is more readily understood is that an athlete should not be exceeding a weekly organised sport participation volume (in hours) that is more than their chronological age (in years) (Brenner et al., 2016; LaPrade et al., 2016). This guideline is supported by two recent case–control studies. First, a retrospective clinical case–control study involving 822 injured and 368 uninjured adolescent athletes (Jayanthi et al., 2015), demonstrated that the athletes who had exceeded the number of organised sport hours (per week) based on their age (in years) during the past year were significantly more likely to have reported an injury of any kind (OR = 1.27), and more specifically, a serious overuse injury (OR = 1.36). Two years later, this finding was supported by another retrospective case–control study, this time with a large population-based cohort of 2011 adolescent athletes (Post, Trigsted, et al., 2017). Within this group, athletes who reported playing more organised sport (hours/week) than their age (years) were again significantly more likely to report a history of any kind of injury (OR = 1.34) or an overuse injury (OR = 1.26).

These studies support the simple weekly volume recommendation of less organised sport hours per week than years of age, which is easily recalled by athletes and their coaches and supporters, making this a more useful message for clinicians to impart. However, this message should be delivered with caution, as neither of these studies address the differences in injury incidence or injury risk between various sports. It is possible that some sports may present higher injury risks than others as weekly participation volume increase. Studies specifically on tennis (Hjelm, Werner, & Renstrom, 2012), acrobatic gymnastics (Purnell, Shirley, Nicholson, & Adams, 2010) and handball (Møller et al., 2017) have all demonstrated positive associations between increasing weekly volume and increased injury, whereas studies on track and field (Huxley, O'Connor, & Healey, 2014), basketball (Gianoudis, Webster, & Cook, 2008), and orienteering (von Rosen, Heijne, & Frohm, 2016) failed to find any statistically significant associations between total weekly participation volume and injury. Whilst these single-sport studies were not specifically analysed with age (in years) as a defining volume threshold, they do suggest that some sports, when practiced more frequently, may present a higher risk of injury than others.

Interestingly, in some of the literature where findings suggest a non-significant association between weekly participation volume and injury, a significant association between weekly participation load (reached by multiplying volume by intensity) and injury has been demonstrated (Huxley et al., 2014; Watson, Brickson, Brooks, & Dunn, 2017). The addition of measuring intensity in injury risk research, which is usually self-rated by a perceived rate of exertion scale, adds another component to the analysis rather than measuring volume alone (Watson et al., 2017). The study by Huxley et al. (2014) suggests that both the intensity and the load of track and field athletes training sessions and competitions, rather than simply the volume of the sessions, is significantly associated with injury in the 13–15-year-old age groups, but not the 16–17-year-olds. A potential problem with this finding is that it relied on data relating to a 5-year period, collected retrospectively. The authors justified their design by citing research that claimed athletes recalled their training history with a reasonable degree of accuracy ($r > 0.73$) (Memmert et al & Baker et al, as cited in Huxley et al. (2014)). However, this research was on adults (mean age 23.3 years), and related only to the recall of volume, not intensity (Baker, Cote, & Abernethy, 2003; Memmert, Baker, & Bertsch, 2010). It is reasonable to question whether an athlete could accurately report an intensity rating, from five years earlier, raising questions about the validity of these results. A similar research question regarding weekly sport load and injury was investigated in a methodologically stronger prospective study on 154 athletes from various sports (Malisoux, Frisch, Urhausen, Seil, & Theisen, 2013). In contrast to the Huxley et al. (2014) study, these authors reported no statistically significant association of total weekly training volume, frequency or load with injury. They did find that a sudden increase in load in the week preceding an injury was a significant factor, and that team sport athletes had a higher risk of injury than individual or racket sport athletes. Recommendations from the Malisoux et al. (2013) study included monitoring of adolescent athletes' workloads, in terms of intensity, frequency and volume. Practically, this type of monitoring of training load is most appropriately suited to performance athlete environments, and is unlikely to be implemented the wider adolescent sport population.

The weekly imbalance between organised sport participation hours and free-play hours has been reported to be associated with serious overuse injuries in one clinically-derived cohort of young athletes (Jayanthi et al., 2015). These seriously injured athletes were 1.7 times more likely to participate in a number of weekly hours of organised sport that was more than twice the number of hours of recreational free-play compared with athletes without serious overuse injury (Jayanthi et al., 2015). However, this association was investigated again two years later, this time in a non-clinically derived athletic population (Post, Trigsted, et al., 2017). In contrast to the Jayanthi et al. (2015) study, these authors found no significant difference in injury outcome between athletes exceeding and not exceeding the 2:1 weekly ratio of organised sport to free-play activity over the past 12 months (Post, Trigsted, et al., 2017). Many experts in the field hold the view that changing sport practices over the past decade have resulted in more hours of deliberate and sport-specific practice, with detrimental consequences, including injury (Bergeron, 2010; Blagrove, Bruinvels, & Read, 2017; Caine, 2010). Unstructured play, or free-play, has been shown to be a significant contributor to better sport performance in young athletes (Coutinho, Mesquita, Davids, Fonseca, & Côté, 2016; Forsman, Blomqvist, Davids, Konttinen, & Liukkonen, 2016; Memmert et al., 2010); however, this type of play is becoming less common, partly due to the high volumes of organised sport commitments (Barreiro & Howard, 2017). Public health messages encourage child and adolescent activity, and yet too much organised sport may be putting adolescent athletes at a greater risk of sustaining a serious injury (Luke et al., 2011). Further research looking at the effects of an imbalanced ratio of structured to non-structured activity in terms of injury is needed.

Months per year participating in organised sport.

Another current guideline relates to limiting the number of months per year an adolescent athlete trains and competes in a primary sport (Brenner et al., 2016; DiFiori et al., 2014; McLeod et al., 2011). Several studies have demonstrated that year-round participation in sport, or even greater than 8 months of participation, in one sport, increases the risk of injury (Cuff et al., 2010; Olsen et al., 2006; Post, Trigsted, et al., 2017). In a large non-clinical case–control study, adolescents who had participated in one sport for more than 8 months of the previous year were significantly more likely to report a history of an injury during that period (OR 1.85; 95% CI [1.50–2.27] $P<0.001$) than those who did not play a single sport for more than 8 months (Post, Trigsted, et al., 2017). A baseball-specific case–control study examining risk factors for serious shoulder and elbow injuries in adolescent pitchers concluded that pitching for greater than 8 months of the year led to a five-fold increase in the odds of sustaining a serious shoulder injury (Olsen et al., 2006). Additionally, a large retrospective cohort study reported that adolescent athletes who played any sport year round (all four seasons) without a break were significantly more likely to report an overuse injury compared with athletes that participated in sport over three or fewer seasons per year (Cuff et al., 2010). Only one study found no significant association between the total number of months of participation in a primary sport (tennis) over the past year and medical withdrawals from tennis matches during a competition season (Jayanthi et al., 2011). Adolescents who had played tennis for greater than nine months had no higher risk of experiencing a medical withdrawal than the athletes who had played tennis for less than nine months. This study used the less common outcome variable of medical withdrawals, which by definition could result from illness or injury. There were a number of limitations to this study. The researchers were unable to obtain the specific reason for withdrawal from the athletes, and so were unable to analyse the injury and volume association specifically. Also, 93.4% of the 540 athletes reported competing in tennis for more than nine months of the year, meaning comparisons with those who competed less than nine months were not statistically strong.

Based on the available literature, it would appear that participating in organised sport for greater than 8 months of the year may increase an adolescent athlete's injury risk. This is another simple message that can be easily delivered in a clinical setting. However, only a limited number of retrospective studies support this statement, highlighting the need for more research investigating this volume association.

Sport exposures over time and injury.

Several investigations into the association between organised sport volume and injury in youth have used alternative and sometimes sport-specific volume exposure definitions. For example, adolescent baseball pitchers who needed shoulder or elbow surgery due to sport-related injuries were investigated in terms of pitches thrown per year (Olsen et al., 2006). The pitchers who needed shoulder or elbow surgery were shown to have thrown significantly more pitches per year than a control group of uninjured baseball pitchers. This, and other similar baseball studies (Fleisig et al., 2011; Lyman, Fleisig, Andrews, & Osinski, 2002), led to the development of specific guidelines for little league baseball pitchers, and the implementation of training guides to inform safe practice and the development of a sport-specific tracking system (McLeod et al., 2011).

In another multi-sport study, participating in ≥30 primary sport competitions (not practices) over a 12-month period was shown to be significantly (OR 1.68; $p < 0.001$) associated with a lower extremity injury (LEI) in 728 (47%) high school athletes compared with 816 (53%) athletes who competed in <30 competitions over the year (Post, Bell, et al., 2017). The odds of reporting a LEI once athletes exceeded 60 primary sport competitions in a year increased even further (OR 2.08; $p < 0.001$). This study was designed to look at the effects of playing for multiple teams in a single sport (i.e. school, representative and club) and found that one in five participants competed in >60 competitions in their primary sport in a year. The competition numbers over a year reported here seem very high, and it is important to bear in mind the possible recall bias of this retrospective cross-sectional study. Also, another potential weakness of this study is the recording of LEI only, when sports such as volleyball and baseball were heavily represented in the sample and upper limb injuries are common in these sports (Seminati & Minetti, 2013; Tolbert, McIlvain, Giangarra, & Binkley, 2011). This may have skewed the data and affected the analyses of the association between exposures and injury. Another study recording volume of participation in terms of exposures found there were 7.5–15 competition exposures per 100 days in their adolescent athletes (Theisen et al., 2013), but an association between higher exposures and injury only existed in team sport athletes. Overall, the results from both of these studies suggest that an increased number of competitions over a year in a single sport, through playing in multiple teams, may increase a young athlete's injury risk. One possible implication of this is that a threshold of 30 competitions over a year for any one sport may be a useful limit for parents and coaches to impose when their young athletes are competing across multiple teams.

2.2.4 Association between volume of sport and overuse injury.

Overuse injuries result from sub-maximal loading of tissues resulting in micro-trauma, leading to pain or difficulty participating to the usual potential (Luke et al., 2011; von Rosen et al., 2016). The logical conclusion would be that a high volume of sport participation would increase the likelihood of sustaining an overuse injury. In the adolescent sport literature included in this review, participation volume is associated with overuse injury in five of the eleven studies where overuse injury was differentiated from acute injuries. Cuff et al. (2010) demonstrated this in a large cohort of 3276 high school athletes. They reported a 42% increased risk of overuse injury in the students who played sport in all four seasons of the year compared with students who had at least one season's break from sport. These results are similar to those of Post, Trigsted, et al. (2017), who reported an association between overuse injury and participation in organised sport for greater than 8 months of the year. These authors also showed an association between participation for more than 16 hours per week in organised sport and overuse injury in the lower extremity only (OR 1.44; $p < 0.01$). A stronger association between weekly sport participation volume and serious overuse injury (OR 2.07; $p < 0.001$) was demonstrated in an earlier study that was based on injured participants recruited from a sports medicine clinic setting (Jayanthi et al., 2015). This study reported significantly more overuse injuries (67.8%) than other similar multi-sport population-based studies: (38%) (Post, Trigsted, et al., 2017); (28%) (Theisen et al., 2013); and (29%) (Cuff et al., 2010). This difference could most likely be due to the recruitment setting, with sport injury clinics attracting a large percentage of overuse injuries. However, two other population-based studies reported seemingly high percentages of overuse injuries: (85%) (Junge et al., 2016); and (50.3%) (Rejeb et al., 2017). Whilst Junge et al. (2016) showed no overall association between the number of sport participations per week and overuse injury, Rejeb et al. (2017) reported a significant association between hours per season of sport participation and overuse injury (RR 1.03; $p < 0.001$).

In five other studies where overuse injury was analysed separately to acute injury in relation to participation volume, no significant association was found (Gianoudis et al., 2008; Huxley et al., 2014; Malisoux et al., 2013; Theisen et al., 2013; von Rosen et al., 2016). The discrepancy between the different studies could be attributed to the variety of injury definitions used. In some studies (Huxley et al., 2014; Malisoux et al., 2013; Theisen et al., 2013), a time-loss definition may have significantly under-reported overuse injuries as many overuse injuries do not immediately result in time off training or competition (Clarsen et al., 2013). However, in other studies, such as von Rosen et al. (2016) and Junge et al. (2016), any report of pain or altered performance have been recorded as an injury, and therefore, these studies will capture more of the growth-related, gradual onset-type injuries.

2.2.5 Section summary.

Organised sport volume, measured in terms of hours/week, months/year and participations or exposures in a specified time period have all been used in studies investigating the association of volume with injury in adolescent athletes. Just over half of the studies identified for this review demonstrated a positive association between increased volume and injury. However, with the variation in study design, outcome measures, injury definitions and ways of rating volume, it is not possible to directly compare findings. Similarly, the association between higher amounts of organised sport volume and overuse injury was found to be significant in five and insignificant in six of the relevant studies. On balance, these results suggest that an association between increased organised sport participation volume and higher injury risk may exist under certain circumstances, and in some populations. Therefore, caution is needed when recommending volume restriction guidelines across the entire adolescent athlete population. There is a need for more research, with clearly defined injury definitions, in populations that represent the everyday adolescent athlete, in order to determine practically applicable volume recommendations.

2.3 Injury Definitions used in Adolescent Sport Research

A range of injury definitions were used in the included studies identified for the two literature reviews. One common way to define an injury was by time lost from sport participation (Boström et al., 2016; Hjelm et al., 2012; Huxley et al., 2014; Jayanthi et al., 2011; Pasulka et al., 2017; Post, Trigsted, et al., 2017; Theisen et al., 2013). Of these, the study with the greatest time-loss required to be recorded as an injury was the one by Huxley et al. (2014), being missing more than three weeks of training or competition. More typical was a one-week loss (Boström et al., 2016; Jayanthi et al., 2011) or one training, competition or game loss (Hjelm et al., 2012; Post, Trigsted, et al., 2017; Theisen et al., 2013). A specific time period of one month for a subset of athletes defined as having a serious overuse injury was also used (Jayanthi et al., 2015; Pasulka et al., 2017). More inclusive injury definitions encompassed any physical complaint affecting performance in their sport (Cuff et al., 2010; Gianoudis et al., 2008; Junge et al., 2016; Malisoux et al., 2013; Møller et al., 2017; Purnell et al., 2010; von Rosen et al., 2016). Several studies required medical attention or diagnosis from a sports-related practitioner to constitute an injury (Jayanthi, 2017; Jayanthi et al., 2015; McGuine et al., 2017; Post, Bell, et al., 2017; Rejeb et al., 2017). Three studies required specific diagnoses, including patellofemoral pain for greater than 12 weeks (Visnes & Bahr, 2013), shoulder or elbow injury requiring surgery (Olsen et al., 2006) and anterior knee pain categorised by diagnosis from a physician (Hall et al., 2015). Only one study failed to define what constituted an injury specifically, and simply asked participants to record "any sport related injury" (Kahlenberg et al., 2016).

Injury definition can have a significant impact on the accuracy of recording the burden of sport-related injury, especially overuse injury (Clarsen et al., 2013). In their 16-week prospective injury surveillance study, the team from the Oslo Sports Trauma Research Centre (OSTRC) trialled a new questionnaire to specifically gain information on overuse injuries. They demonstrated a significant number of overuse injuries (n = 379) in the 313 adolescent athletes. They also illustrated the under-reporting when following accepted consensus guidelines for injury surveillance, which defines injury by time-loss or needing medical attention (Fuller et al., 2006). Using this time-loss or medical diagnosis method, Clarsen and colleagues from the OSTRC group only recorded 40 overuse injuries in the same group of athletes (Clarsen et al., 2013).

Injury definition is an important consideration, and essential to clearly define, in any research investigating the association of potential and known risk factors with injury in sport.

In New Zealand, there have been no studies published that investigate early specialisation in adolescent sport, and thus, the degree of specialisation amongst our young athletes is not known. Additionally, it has been established overseas that there is an association between specialisation and injury, and between high organised sport participation volumes and injury in adolescent athletes, but it is unknown if this association occurs in NZ children, or if it occurs specifically in the early adolescent age group.

Chapter 3: Methods

Introduction

For this research, a group of New Zealand children aged between 10–13 years were surveyed, and data was collected on sport specialisation, organised sport participation volume, and non-organised activity volume and injuries sustained over the previous 12 months. Demographic data were also obtained including school size and decile. The surveys were completed by athletes attending the New Zealand Association of Intermediate and Middle schooling (NZ AIMS) games, a large week-long sport competition for intermediate school children. This chapter will outline the methods used for this research, including the study design and its rationale, study setting, participants, questionnaire development, recruitment process, data collection, data recording, variable definition and data analysis.

3.1 Study Design

This study was a retrospective cross-sectional study and used a paper-based survey research strategy to collect information relating to the previous 12 months from the cohort of early adolescent athletes attending the 2017 NZ AIMS games. All data collected were quantitative in nature. The study contained both descriptive and analytical elements. Within health research, cross-sectional studies are perceived to be an excellent way to determine prevalence of health outcomes and associations between these outcomes and possible risk factors (Graham, 2010; Mann, 2003). The cross-sectional method of research is useful to give an overview of a population, and although causation cannot be established from cross-sectional data, patterns of participation, associations between risk factors and injury and inference to causation can be established (Bowling, 2002). This research will potentially provide valuable information to inform researchers and health professionals of the current status of specialisation and organised sport participation hours in 10–13-year-old NZ children. This information can then help researchers decide if more expensive and time-consuming prospective studies are warranted. Results from this study may aid to inform clinicians about recommendations for sport volume and practice ideally as part of an injury prevention programme.

3.2 Study Setting

The NZ AIMS games are a large national sporting championship held over a six-day period, in a tournament format. The 2017 games offered 21 different sporting codes, including both team and individual sports (Anchor AIMS games, 2018). The NZ AIMS games promote participation or the opportunity to compete at an elite level against the best middle-school aged athletes throughout New Zealand (Anchor AIMS games, 2018). The source population for this study consisted of all the registered athletes participating in the 2017 NZ AIMS games. This tournament was held in the city of Tauranga which is situated on the east coast of the North Island of NZ between Sunday 10th and Friday 15th September 2017. Four different sites were visited by the researchers over a three-day data collection period (September 11–13) and included grass sports fields, indoor arena and courts, indoor pools, outdoor courts and artificial turfs. The sports being played at the venues visited by the researchers included tennis, rugby, netball, hockey, basketball, water polo, soccer, futsal and swimming. Some athletes surveyed at these venues were in attendance as supporters outside of their own sport participation hours, and so sports not listed above were also recorded. They were all verified as AIMS competitors. The four sport locations were chosen because they had the largest variety of team and individual sport representation at the games.

3.3 Participants

Participants were eligible for inclusion in the study based on their registration as an athlete for the 14th NZ AIMS games. The total research population consisted of 10,139 athletes, from 303 New Zealand schools (V. Semple, personal communication, February 26, 2018). To participate in the NZ AIMS games, athletes needed to be aged 10, 11, 12 or 13 years, and in the intermediate or middle school years seven and eight.

3.3.1 Sample size.

One-thousand completed surveys were targeted. The total number of athletes attending the games in 2016 was 9,300, and there were an estimated 10,000 athletes enrolled for the 2017 games at the time of the study design process. To ensure the sample size would be statistically large enough to be representative of the population, an online sample size calculator was used (*The survey systems sample size calculator,* 2012). In epidemiological research, it is common to tolerate a 3–5% margin of error (Denscombe, 2010). Assuming a 95% confidence level and a margin of error of 5%, a sample size of 370 would be required whereas a 3% margin of error would require a sample size of 964, in a population of 10,000. Sampling technique was based on voluntary participation, and although all athletes attending the venues had equal opportunity to participate, only those who attended the selected locations over the three days were likely to participate.

3.3.2 Ethical and cultural considerations.

Ethical approval was sought through Auckland University of Technology Ethics Committee (AUTEC) and was approved on 28th June 2017 (application number 17/179). Any NZ AIMS registered athlete (from NZ schools only) in attendance at the sites visited by the researchers during the three-day collection period was eligible to participate in the research.

Consent.

By volunteering to complete a survey, the participants were consenting to the information they provided being used for this research project. This information was displayed at the start of the survey (see Appendix B), and in the information sheet provided to each participant once they volunteered to participate (see Appendix C). Parental consent was not sought, due to the recruitment taking place over a single sporting competition where many athletes were in attendance without parents. As this study was considered low risk (non-interventional), neither written nor proxy consent were deemed necessary by AUTEC, providing the child was competent to understand the nature and consequences of the research (Peart, 2007).

Protection of the child.

In order to ensure the protection of the child and ensure no coercion or imbalance of power was present, direct approach of an athlete was not allowed. This is in keeping with current recommendations for ethical health research with children in New Zealand (Powell & Smith, 2006), and as approved by AUTEC.

3.4 Recruitment and Data Collection

Recruitment and data collection took place on site at four sporting locations in Tauranga /Mount Maunganui over a consecutive three-day period (September 11–13th, 2017) and included Blake Park, Baypark Arena, Baywave Aquatic Centre and Waipuna Park. All registered athletes attending the NZ AIMS games were eligible to participate in the research. Participation in the research was voluntary and information obtained was anonymous. Information sheets (see Appendix C) were available at two separate athlete ‘chill zones’ set up at the major outdoor venue (Blake Park, Mount Maunganui). A team of eight research assistants were employed to collect the data at four different venues during the sport participation times. A self-completed and part interviewer-assisted data collection method using a paper questionnaire was utilised. Face-to-face interview by a research assistant for any athlete who reported an injury took place. By using the face-to-face collection method, data was able to be verified and collected until the required sample size was met; this also helped to limit non-response bias (Denscombe, 2010; Schofield & Knauss, 2010). Previous researchers looking at a similar research topic, who used internet-based surveys or postal surveys, reported a high percentage of non-responders (Cuff et al., 2010; Kahlenberg et al., 2016).

A non-probability sampling technique was selected. This technique was most appropriate for an on-site survey at a tournament setting, where a pre-determined randomly selected sample would be impossible to locate at the many different locations. Instead, each research assistant was located at one of the sports sites, and they were instructed to discuss with team coaches or the supervising adults the nature of the research project. The adults were then able to invite their athletes to participate in the research project. This technique could be described as maximum variation purposive sampling, which is when the researcher uses their judgement to deliberately include a wide variety of participants that meet the criteria of their target population (Lavrakas, 2008). This was the rationale used when selecting which locations to place research assistants at, in order to obtain a varied sample of the most commonly practiced sports in NZ.

3.5 Survey Development

There is no validated measure to rate specialisation or a universally agreed measure to record participation volume. Therefore, a questionnaire was developed specifically for this research project, informed by previous overseas research in a similar area (Jayanthi et al., 2015; Pasulka et al., 2017; Post, Trigsted, et al., 2017; Siesmaa et al., 2011). A pilot study was also conducted (in a clinic setting) in the year prior to this project using a written questionnaire, and feedback from this was utilised in the re-design of the questionnaire for this current research. The final questionnaire contained three sections: demographic data, sport participation data and injury history (see Appendix B). The sport participation section included questions relating to specialisation, participation volume and recreational free-play hours. Demographic data asked for age in years and months, school year, gender and school name. School name was included to record each participant's school size, as previous research has indicated that specialisation is more prevalent in larger schools (Post, Bell, et al., 2017). School decile was also recorded, as we were interested to investigate if specialisation was more prevalent in schools with a higher decile. Decile rating in NZ is applied to state-funded schools and is relative to the socio-economic position of the school community (2017). A school with a decile rating of '1' receives the most government funding and represents the 10% of schools in the lowest socioeconomic area. The highest rating, a decile '10', represents the 10% of schools in the highest socioeconomic regions (2017). Opportunity for adolescents to participate in many sports at a highly specialised level requires a definite financial commitment from families (Bodey, Judge, & Hoover, 2013), which means socioeconomic background may influence the prevalence of specialisation on both extremes of the scale.

The final questionnaire was presented as a double-sided single sheet of paper. It took approximately 5–10 minutes to complete and consisted of 13 questions.

3.5.1 Specialisation questions.

A scale to rate the degree of specialisation was first used by Jayanthi et al. (2015) and consisted of three questions with a 'yes' or 'no' response. A point was awarded to every 'yes' response. An athlete who scored 3 points was rated 'high specialisation', an athlete who scored 2 points was rated 'moderate specialisation' and an athlete with either a '1' or '0' was rated 'low specialisation'. The three questions in this scale were: 1. "Can you pick a main sport?"; 2. "Did you quit other sports to focus on a main sport?"; 3. Do you train for more than 8 months in a year?". This scale to rate the degree of specialisation has since been used in many international research studies, with some small changes in wording and question format (Jayanthi et al., 2015; McGuine et al., 2017; Pasulka et al., 2017; Post, Bell, et al., 2017; Post, Thein-Nissenbaum, et al., 2017; Post, Trigsted, et al., 2017). No study has, however, looked at the reliability of these questions, especially when answered by a child.

In this study, we used a modification of the scale presented by Jayanthi et al. (2015) that included four questions, with a total possible score of 3 (see questions 5–8 on questionnaire, Appendix B) and resulted in the same ratings of high, moderate or low specialisation. The additional question was added, based on recommendations by Pasulka et al. (2017), who identified that the previous three-question scale had failed to correctly categorise a subset of athletes who had only ever competed in one sport, and in essence, were highly specialised. Feedback from our clinic-based pilot study, which had used the three questions originally published, also led to some minor changes in wording, better suited to 10–13-year-old NZ athletes.

3.5.2 Test-retest reliability study for specialisation scale.

A small test–retest reliability study was conducted for the specialisation questions used in this research. This was conducted to ensure that a) the children understood the questions and b) the questions could reliably rate specialisation status.

A local school listed to attend the NZ AIMS games was contacted in July 2017 and asked to be involved in the reliability study. The school had 51 children registered to attend the AIMS games in 2017. On two separate dates, four weeks apart in August 2017, the children were asked to answer the four specialisation questions under the supervision of the school sports administrator. The time of four weeks was chosen as it was unlikely any changes in sport practices and participations would have occurred, but it was long enough that the children would not simply repeat answers based on recall. This timeframe is in keeping with another test–retest reliability study conducted on youth cricket players regarding sport participation and injury history (Siesmaa et al., 2011). Each student's responses were recorded against a unique number for both the initial and second time they answered the questions. This information, which was therefore anonymous, was then passed on to the researcher for analysis.

A total of 23 children completed both the initial and four-week repeat questions. The reliability of both the total score and each individual question was assessed. The intraclass correlation coefficient (ICC) statistic (two-way mixed effects model) was calculated to assess reliability of the total score. An ICC of 0.85 was reached, suggesting very high agreement based on a previously published classification of the ICC (Hinckson, Hopkins, Aminian, & Ross, 2013). The level of agreement for each individual question was assessed by calculating the percent agreement and kappa coefficient. Question 1 had 87% agreement and a kappa score of 0.43. Questions 2 and 3 had a 90% agreement and Kappa scores of 0.67. Question 4 had a 100% agreement, and a kappa score of 1.00. All statistics were computed using IBM SPSS software (version 24).

Based on these scores, and feedback from the athletes, wording of the second question was altered slightly in the final survey version, by removing the word "main" to clarify the question. Several children had misunderstood question 2 thinking it related only to a 'main sport' referred to in question 1.

Overall the percent agreement suggests good agreement for all the individual questions and the kappa scores suggest question 1 had moderate agreement, questions 2 and 3 had substantial agreement, and question 4, perfect agreement (Landis and Koch, 1977). While a full discussion is beyond the scope of this chapter it should be noted that many authors have identified the paradox of kappa where high percent agreement is coupled with relatively low kappa values (Feinstein and Cicchetti 1990) and this may be evident in our findings for question 1.

3.5.3 Participation volume.

Average weekly participation in organised sport competitions and training sessions was collected via a single table (Question 9 see Appendix B). This table had been simplified following the pilot survey feedback, which had two separate tables for winter and summer seasons. Pilot study participants had commented this had been too time consuming, and there had been a lot of repetition. Other research using surveys to collect adolescent athletes' previous history regarding organised sport volume have used a variety of methods. Some used multiple questions covering all volume measures (Kahlenberg et al., 2016; Malisoux et al., 2013), others asked the athlete to estimate an average weekly number (Cuff et al., 2010; Jayanthi et al., 2015). Because retrospective surveys are subject to recall bias, it was important that we collected data as accurately as possible. It was felt that having a table with a space to record participation for each week day would help the athlete to recall what they had previously done by systematically working through their week. Simple codes were provided to minimise writing time, which is an important consideration in survey research (Schofield & Knauss, 2010).

In the final survey, each weekday had a box, where the athlete was required to write what sports were played, either as competitions or games. They were also required to write, in hours and minutes, the typical time spent with each competition or practice. Each entry was then coded with an S for summer (school terms one and/or four), W for winter (school terms two and/or three) and AY for all year (if a sport spanned more than two school terms). Research assistants were trained to check each survey to ensure the athlete had completed hours and season detail by each entry.

3.5.4 Free-play.

A single numerical value (in hours or part thereof) was requested that represented an average weekly non-organised or free-play participation time. Examples were given and research assistants were trained to explain the concept of ‘free-play’ to the athlete if they needed assistance. Previous researchers who recorded this data had also used self-estimated time questions (Jayanthi et al., 2015; Post, Trigsted, et al., 2017); however, the definition of free-play varied. In previous research, free-play often included 'gym class' at school. Following a review of the literature, it was decided that, for the purpose of this research, only physical activity that was not organised or moderated by an adult and that occurred out of school hours would be included. The examples given of the non-organised activities included skateboarding, surfing, playing at a park with friends, climbing trees, bike riding, playing at playgrounds.

3.5.5 Injury data.

Sport-related injury history was recorded for the past 12 months only, to minimise recall bias, in keeping with previous research (Boström et al., 2016; Cuff et al., 2010; Post, Bell, et al., 2017; Post, Trigsted, et al., 2017). Injury questions were asked to identify injuries that led to loss of time playing sport, as well as injuries that the athlete continued to play through. A body chart was provided, and children who reported a history of injury were required to circle the area injured on the body chart, and then discuss each injury with a research assistant. This approach was implemented to improve the accuracy of injury reporting.

3.5.6 Injury definitions.

Time-loss injuries were defined as any injury sustained while playing sport that led to at least one day of missed training or competition. Play-through injuries were defined as injuries that caused pain or discomfort for longer than a day, but did not result in loss of time from sport.

Acute injuries were defined as an injury that occurred as the result of a sudden event, causing immediate symptoms. This was then further refined as either contact or non-contact in nature. Contact injuries involved another person, or fixed object colliding with the injured body part. Non-contact injuries occurred in response to momentum, twisting or turning, such as rolling an ankle or straining a knee.

Gradual onset injuries were defined as being not induced by a sudden event, resulting in reduced training capacity, experience of pain, difficulties participating in sport, or reduced performance. The onset is gradual, and can be very slow, over weeks or months, or can occur over the duration of a single game or training session.

3.5.7 Injury classification.

Research assistants were trained to ask each athlete who reported a history of injury specific details pertaining to that injury so that they could be coded as acute contact, acute non-contact or gradual onset. All research assistants were provided with a one-page document defining each category, and with examples of diagnoses (see Appendix D). This was discussed at an initial training session with the research assistants and they had an opportunity to ask questions. Research assistants coded each injury using a numerical representation on the body chart that corresponded to the grey box on page two of the survey.

3.6 Data Recording

Each completed questionnaire was allocated a unique participant number. Raw data were manually transferred to a cloud-based secure Excel spreadsheet by the primary researcher and two research assistants. Information regarding the transfer of data was provided to each of the research assistants and a training session was provided (see Appendix E). Excel data were then reviewed, and incomplete data sets, or participants who did not meet the inclusion demographics, were removed. An exception was made for missing free-play data (question 10) because 121 participants did not complete this question. Rather than eliminate these participants from the entire sample, a subset of data for the 793 participants who did answer question 10 was created and analysed separately to answer research question 3, regarding the ratio of organised to free-play participation volume.

Demographic data were recorded as follows. Age was entered as month and year, and was then converted to a decimal number to reflect current age, based on September 2017 as the date of collection. School name was provided by the participant. Using data from the Ministry of Education website (Alexander, 2017), school size (number of enrolled students) and decile (1–10) were obtained for each participant. School year was recorded as either year seven or eight.

Specialisation data was recorded as a '1' for a 'yes' response and a '0' for a 'no' response for each of the four specialisation questions. A total score out of three was then computed and entered (note questions 3 and 4 could only give a maximum of 1 point due to only answering question four if a 'no' response was given in question 3). Using the raw score, each athlete was categorised by the degree of specialisation (low=0–1, moderate=2 or high=3).

Organised sport participation volumes were extracted from the table in question nine (see Appendix B), and recorded as hours or part thereof. These were recorded as average weekly winter hours, average weekly summer hours, and average weekly all-year hours. Average weekly hours of participation for each athlete over the previous 12 months was derived by adding summer hours and all-year hours, and winter hours and all-year hours, then finding an average of the two. For children who were categorised as either moderate or high in the specialisation section and answered 'yes' to the first specialisation question (which asked if they had a main sport), the sport for which they participated in for the most hours in a week was recorded in a separate column as their main sport. Free-play average weekly hours, or part thereof were recorded as a decimal number. An Excel equation was used to record a 'yes' or 'no' for each participant regarding the volume-based analysis of participating in more organised sport hours/week than chronological age. A similar column was added to the data set who answered the free-play question, where a 'yes' was recorded for athletes who participated in a >2:1 ratio of organised weekly hours compared to free-play hours. Question 7 (part of the specialisation questions) was used to separate the athletes who participated in one sport for more than 8 months of the year from those who did not.

Injury data were recorded for each participant as a 'yes' or 'no' for sustaining 'any injury' in the 12-month period, a 'yes' or 'no' for sustaining a 'gradual onset injury' in the 12-month period and a 'yes' or 'no' for sustaining an 'acute injury' in the past 12 months. The total number of injuries and the number of injuries per site were also recorded for each participant and used for descriptive purposes. The sites were divided into eight regional sections including: hip and upper leg; knee and lower leg; ankle, foot and toes; neck, spine or torso; head, jaw or face (including concussion); shoulder and upper arm; elbow and forearm; wrist, hand and fingers.

3.7 Variable Definitions and Recoding

The main dependent (outcome) variable from this data is a dichotomous variable of whether a participant sustained any injuries in the previous 12 months or not. Separate analyses were conducted for all three injury definitions: 1. Any injury sustained or not; 2. Any gradual onset injury sustained or not; 3. Any acute injury sustained or not.

The main independent (explanatory) variables in this study included specialisation and participation volume. Specialisation is a categorical variable, with three categories (low, moderate and high). Participation volume was analysed as a continuous variable (hours per week), as well as by three dichotomous ('yes' or 'no') variables based on the following: 1. Did the child play one sport for more than 8 months of the year?; 2. Did the child participate in more organised sport per week (in hours) than their age (in years)?; and 3. Did the child participate in more than twice the amount of organised sport to free-play activity each week?

Additional potentially confounding independent (explanatory) variables included age, school size, decile and gender. These variables were all recoded to create categorical variables for inclusion (where applicable) in the multiple logistic regression analyses. Each participant was categorised as coming from a small (<500 students), average (500–999 students) or large (≥1000 students) school based on overall NZ school size (Alexander, 2017) and in keeping with previous research (Post, Bell, et al., 2017). For decile ratings, participants were grouped as high (8–10), medium (4–7) or low (1–3) decile. Participants were also grouped into three categories by age, as <12 years, between 12 and 13 years, or >13 years. Gender was recorded as male or female.

3.8 Data Analysis

All statistical data analyses were completed using the Statistical Programme for Social Sciences (SPSS) (IBM SPSS, Chicago), version 25.

Descriptive statistics pertaining to the sample are tabled in four parts. Mean and standard deviations are given for continuous variables with a normal distribution, and a median and range is given if the continuous variable is not normally distributed. Frequencies and percentages are reported for all categorical variables. The four sections of descriptive statistics are:

1. Demographic data including age, gender, school size, school year and school decile.

2. Specialisation data including frequencies and percentages for each specialisation question as well as a point prevalence of high, moderate and low specialisation. Specialisation per main sport is also reported.

3. Organised sport participation volume measures, including a description of the average hours practiced within specific sports and an analysis of the participation hours between each specialisation group.

4. Injury data are presented as a total number for the sample, as well as reporting injuries by type, by location and by sport. An injury frequency has been calculated for each main sport identified by moderately and highly specialised children. This was calculated by dividing the total number of injuries reported by each child who specialised in that sport, by the number of children identified as specialising in that sport.

Inferential statistics were used to investigate the associations between the study independent variables and the various types of injury. In order to control for potential confounding variables, separate analyses were initially conducted to determine the relationship between each potential confounding variable and each injury type (see Appendix F). Chi-square tests for independence were used to determine if there were statistically significant differences between each confounding variable group and sustaining each injury type (Barton & Peat, 2014). A less restrictive alpha level of 0.1 was considered significant for inclusion in the major analyses (Lang & Secic, 2006).

To investigate the associations between the study independent variables and injury, univariate logistic regression analyses were initially conducted. Odds ratios with a 95% confidence interval (CI) were calculated from these tests and presented as unadjusted odds ratios. A p value of <0.05 was considered a statistically significant association.

To further analyse these associations, multiple logistic regression models were built to examine the effect of each of the independent (explanatory) variables on each type of injury while adjusting for the potential confounders identified for each injury definition. Organised to free-play ratio analysis was conducted only on the subset of children who answered this question (n=793). The block entry method was used when creating the multiple logistic regression models, as this allowed forced entry of the study variables, and block by block entry of the potential confounders. The forced entry method is the most appropriate logistic regression method when testing a specific theory according to Field (2005), whereas stepwise entry methods are used when exploring data for previously un-reported associations. Adjusted odds ratios with a 95% CI were calculated from these analyses to estimate the relationship between specialisation and the various measures of participation volume and the likelihood of reporting a history of 'any injury', an 'acute injury' or a 'gradual onset injury'. As well as the adjusted odds ratios presented in the Results section, Appendix G provides a full summary of the predictive strength of each multiple logistic regression model, including the β coefficient, standard error, Wald χ^2 test statistic, associated *p* value and effect size (pseudo R^2 statistics), as recommended when reporting multiple logistic regression by Lang and Secic (2006) and Field (2005).

Chapter 4: Results

Introduction

This chapter is presented in three sections. The first section presents the descriptive statistics of the survey data, including demographics, specialisation prevalence, participation volume and injury characteristics. Section two highlights the results of the investigations looking at the association between specialisation and injury. The final section presents the results from the analyses of the associations between participation volume and injury.

4.1 Participant Characteristics

A total of 925 surveys were completed during the three-day data collection period. Eleven surveys were removed due to participants being outside the included school year range (*n*=5), having incomplete times on the participation hour table (*n*=4), and being from a non-NZ school (*n*=2). The remaining 914 surveys were included in the major analyses. Of these, 121 children did not answer question 10, which related to weekly free-play hours. These 121 surveys were excluded when analysing the association between exceeding organised sport: free-play recommendations, leaving 793 for this analysis (section 4.3.4).

4.1.1 Demographics.

The sample was made up of 538 female (59%) and 376 male (41%) children. The mean age was 12.6 ± 0.5 years (range 10.8–13.9 years). All children were either in year 7 (*n*=329; 36%) or year 8 (*n*=585; 64%) and attending a NZ school. Decile representation was weighted towards the higher end with 426 (46%) attending decile 8–10 schools (high decile), and only 134 (15%) children attending decile 1–3 schools (low decile). The school size, based on the number of enrolled students, ranged from 41 pupils to 1961 pupils. Children who attended a small school (<500 pupils) represented 33% of the sample. Children who attended a medium sized school (500–999 pupils) represented 47% of the sample. Children who attended a large school (≥1000 pupils) represented 20% of the sample.

4.1.2 Specialisation data.

Four questions (Questions 5–8 on the survey, see Appendix B) were specific to categorising specialisation. In response to the first question regarding specialisation, "Can you choose one main sport that is more important than others?", 248 children responded 'no' (27%) and 666 responded 'yes' (73%). In response to the second question, "Did you train/compete more than 8 months out of the year in one sport?", 208 responded 'no' (23%) and 706 responded 'yes' (77%). In response to the third question, "Have you only ever trained/competed in just one sport?", 719 responded 'no' (79%) and 195 responded 'yes' (21%). For the 719 who responded 'no' to this question, a further question was asked. This was, "Have you quit all other sports to focus on one main sport?" and 571 responded 'no' (79%) and 148 responded 'yes' (21%).

A total of 231 children within this sample were categorised as highly specialised (answered 'yes' to three questions), giving a point prevalence of 25%. The majority of children (*n*=395) were categorised as moderately specialised (answered 'yes' to two questions) giving a point prevalence of 43%. The remaining 288 children were classified into the low specialisation group (answered 'yes' to one or none of the questions), giving a point prevalence in this sample of 32%.

The sport with the highest weekly participation volume was recorded for each child in the sample who was categorised as highly or moderately specialised and answered 'yes' to choosing a main sport (Question '5' in the survey). Table 4.1 presents the main sport identified for the 357 moderately and 231 highly specialised children, as well as the relative frequencies (%) of highly specialised and moderately specialised children for each sport.

Table 4.1 *Main sport played by moderate and highly specialised children*

Sport*	Moderate specialisation *n (%)*#	High specialisation *n (%)*#
Gymnastics	3 (50)	3 (50)
Basketball	64 (56)	51 (44)
Tennis	19 (56)	15 (44)
Netball	54 (58)	39 (42)
Football	100 (61)	65 (39)
Rugby	42 (61)	27 (39)
Swimming	19 (66)	10 (34)
Waterpolo	9 (69)	4 (31)
Hockey	22 (71)	9 (29)
Other^	15 (75)	5 (25)
Futsal	10 (77)	3 (23)
Total	357 (61)	231 (39)

* Only sports where there were >5 participants have been tabled separately. ^ Other includes dance, equestrian, bowls, golf, softball, cricket, rugby league, athletics, martial arts, cheerleading, touch rugby. # Relative frequency of moderate compared to highly specialised, or high compared to moderately specialised.

4.1.3 Organised sport volume data.

The median weekly organised sport participation volume over the 12 months per child, was 4.4 hours (range 0.25–38). Broken down into seasons, the summer weekly median was 3.0 hours (range 0–38), and the winter weekly median was 6.0 hours (range 0–38).

The number of children who reported more hours of organised sport per week than their age in years was 42/914 (5%). The number of children that exceeded a ratio of 2:1 weekly organised sport hours to weekly recreational free-play hours was 231/793 (29%). The number of children who exceeded the recommended maximum months (>8) per year for a single sport was 706/914 (77%).

The median weekly organised sport participation hours for the high specialisation group was 4.0 (range 0.5–38); that for the moderate specialisation group was 4.5 (range 0.25–23.5); and that for the low specialisation group was 4.5 (range 0.5–23.5). Because the weekly volume data were not normally distributed, the differences among the three specialisation groups were tested using the Kruskal-Wallis rank test (Field, 2005); there were no statistically significant between-group differences in weekly participation hours (p = 0.09).

The median weekly participation hours averaged over the full year, as well as by season, for the main specialised sports are presented in table 4.2.

Table 4.2 *Median weekly participation hours per child for each specialised sport*

Sport*	**Winter Season Median (IQR)**	**Summer Season Median (IQR)**	**Full year Median (IQR)**
Gymnastics	17 (7.5–20.5)	12 (5.5–18.3)	13.1 (8–18.4)
Tennis	9 (6.5–10.9)	8.5 (6.5–12)	8.5 (5.9–11.8)
Waterpolo	9.3 (7–11)	6.5 (4.8–9.5)	7.8 (6.5–10)
Swimming	8.6 (5.5–12)	7.5 (5.5–12)	7.5 (5.3–11.1)
Futsal	6 (4.5–8.9)	2.5 (1–4.6)	5 (3–5.5)
Basketball	6 (4–8.5)	3 (1–6)	4.5 (2.5–6.5)
Football	5.5 (4–8)	2.5 (0–4.6)	4 (2.5–6.3)
Hockey	5.5 (3.9–8.5)	1 (0–2.5)	3.9 (2.1–5.6)
Rugby	5 (4–8)	0.5 (0–3.5)	3.5 (2.5–5)
Netball	4.7 (3–7)	1 (0–2.7)	3 (1.8–5)

* Only sports with >5 highly or moderately specialised participants are included in the table. IQR: *Inter-quartile range*

4.1.4 Injury data.

A total of 1,536 unique sport-related injuries were reported as occurring over the previous 12 months. The majority (74%) of the children reported at least one injury. For the 680 children who reported an injury, the median number of injuries per child was two (range 1–12).

Acute injuries accounted for 78% of the total injuries (n = 1,204) and gradual onset injuries accounted for 22% of the total injuries (n = 332). Acute injuries, when broken down into non-contact and contact injuries, represented 41% (n = 636) and 37% (n = 568) of the total injuries respectively. There was a median of 1 (range 1–6) gradual onset injuries per child who reported a history of this type of injury. For acute contact injuries the median was 1 (range 1–9) per child and for acute non-contact the median was 1 (range 1–10) per child.

Of the 680 children who reported an injury in the past 12 months, 385 children reported both time-loss and play through injuries, 117 reported only play through injury/injuries, and 178 reported only time-loss injury/injuries.

Table 4.3 presents an overview of the injuries reported by location. Overall, the lower limb was injured more frequently (62%) than the upper limb (26%) or the head and torso (12%).

Table 4.3 *Frequency of reported injuries by body site*

Site injured	Number of injuries (n)	Relative frequency (%)
Ankle/foot/toes	491	32
Knee/lower leg	315	21
Wrist/hand/fingers	215	14
Hip/upper leg	145	9
Spine/torso/neck	131	8
Shoulder/upper arm	126	8
Elbow/forearm	58	4
Head/face	55	4
Total	**1536**	**100**

Table 4.4 shows all injuries sustained by moderate and highly specialised children per main sport. An injury rate per child is also reported for each sport. Only sports where >5 injuries were reported are shown in the table. Gymnastics and martial arts had the highest injury rates.

Table 4.4 *Any injuries sustained per main sport*

Sport	Injury frequency (*n*)	Specialised children (*n*)	Injury rate per child
Gymnastics	38	8	4.75
Martial arts	9	2	4.50
Rugby league	7	2	3.50
Waterpolo	27	14	1.93
Rugby	130	73	1.78
Tennis	62	35	1.77
Basketball	196	119	1.65
Football (soccer)	283	173	1.64
Hockey	59	37	1.59
Swimming	46	30	1.53
Netball	151	102	1.48
Total	**1008**	**595**	**–**

Note: Specialised children include moderate and high categories of specialisation

4.2 Association between Specialisation and Injury

4.2.1 Specialisation and 'any injury'.

No statistically significant differences in the proportions of children sustaining an injury in the previous 12 months were found between the low, moderate and high specialisation groups (Pearson's χ^2 = 2.63; p = 0.27). The relative frequency of injured children per specialisation group is shown in Figure 4.1.

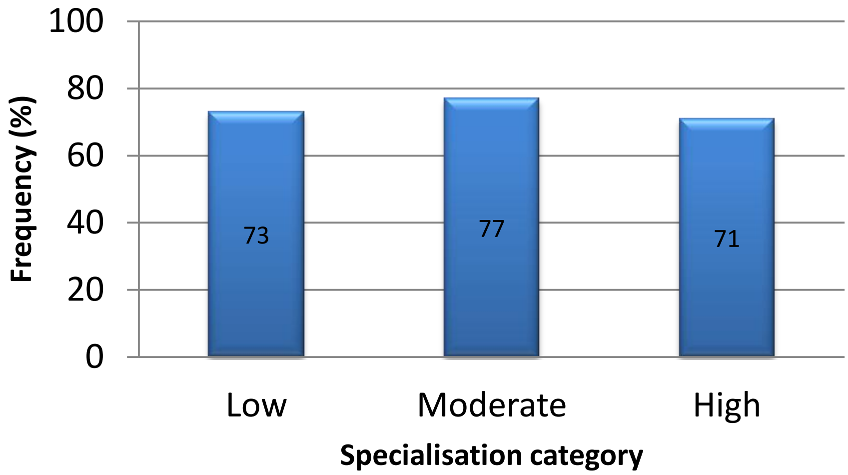

Figure 4.1. Relative frequencies of children reporting a history of 'any injury'.

Unadjusted and adjusted odds ratios (OR) for reporting 'any injury' based on specialisation category are presented in Table 4.5, and confirm that there were no statistically significant associations between these variables, even when adjusting the model for the potential confounding variables (school size and decile) and participation volume. A summary of the predictive strength of the multiple logistic regression model examining this association can be found in Appendix G, Table G1.

Table 4.5 *Association between 'any injury' and specialisation*

Specialisation category	**Unadjusted*** **OR (95% CI)**	***p*** **Value**	**Adjusted**** **OR (95% CI)**	***p*** **Value**
Low	-	-	-	-
Moderate	1.31 (0.93–1.85)[a]	0.12	1.15 (0.80–1.65)[a]	0.45
High	0.80 (0.52–1.21)[a]	0.28	0.88 (0.59–1.31)[a]	0.53

OR, odds ratio. *Univariate logistic regression analysis. **Multiple logistic regression analysis model adjusted for participation volume (in hours/week), school size (categorical) and decile (categorical). [a] The reference group for analysis was the low specialisation group.

4.2.2 Specialisation and 'gradual onset injury'.

A statistically significant difference in the proportions of children reporting a history of 'gradual onset injury' in the past 12 months was found between specialisation groups (Pearson's $\chi^2 = 7.02$; $p = 0.03$). Figure 4.2 shows the relative frequencies of children reporting a 'gradual onset injury' in each specialisation category. The largest between-group difference (10%) was between the moderate and high specialisation categories.

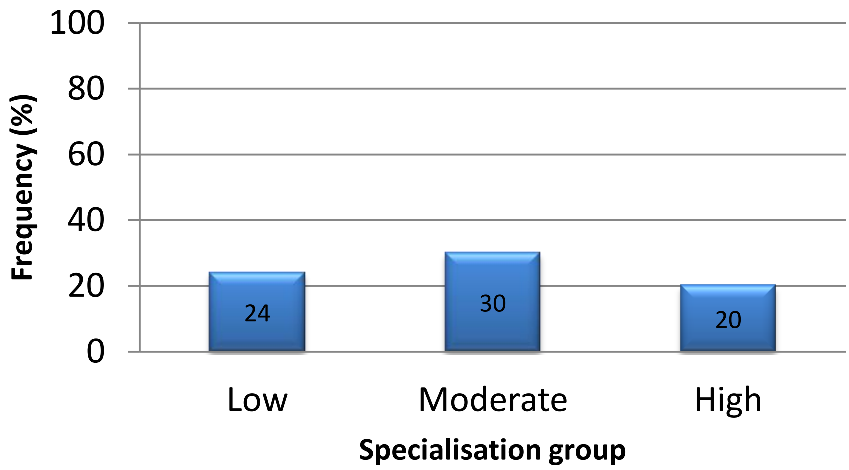

Figure 4.2. Relative frequencies of children reporting a history of 'gradual onset injury'.

This relationship remained when tested in a multiple logistic regression analysis that adjusted for confounding variables (school size, age and decile) and participation volume (see Table 4.6). Children who were moderately specialised had 1.72 times the odds of reporting a history of 'gradual onset injury' compared with highly specialised children. Being highly or moderately specialised did not significantly increase, or decrease, the odds of a child reporting a history of 'gradual onset injury' compared with having a low degree of specialisation, even when adjusting for confounding variables. A summary of the predictive strength of the multiple logistic regression model examining this association can be found in Appendix G, Table G1.

Table 4.6 *Association between 'gradual onset injury' and specialisation*

Specialisation category	Unadjusted* OR (95% CI)	*p* Value	Adjusted** OR (95% CI)	*p* Value
Low	1.26 (0.83–1.91)[b]	0.28	1.34 (0.87–2.06)[b]	0.19
Moderate	1.65 (1.12–2.43)[b]	**0.01**	**1.72 (1.15–2.56)[b]**	**0.01**
	1.31 (0.93–1.90)[a]	0.12	1.29 (0.90–1.84)[a]	0.17
High	0.80 (0.52–1.21)[a]	0.28	0.75 (0.49–1.15)[a]	0.19

OR, odds ratio. $p < 0.05$ is statistically significant **(Bold font).** *Univariate logistic regression analysis. **Multiple logistic regression analysis model adjusted for participation volume (in hours/week), school size (categorical), age (categorical) and decile (categorical). [a] The reference group for analysis was the low specialisation group. [b] The reference group for analysis was the high specialisation group.

4.2.3 Specialisation and 'acute injury'.

No significant between-group differences were seen in the proportions of children reporting a history of 'acute injury' between specialisation groups (Pearson's $\chi^2 = 0.40$; $p = 0.82$). Figure 4.3 illustrates the relative frequency of the children who reported a history of an 'acute injury' in each specialisation group.

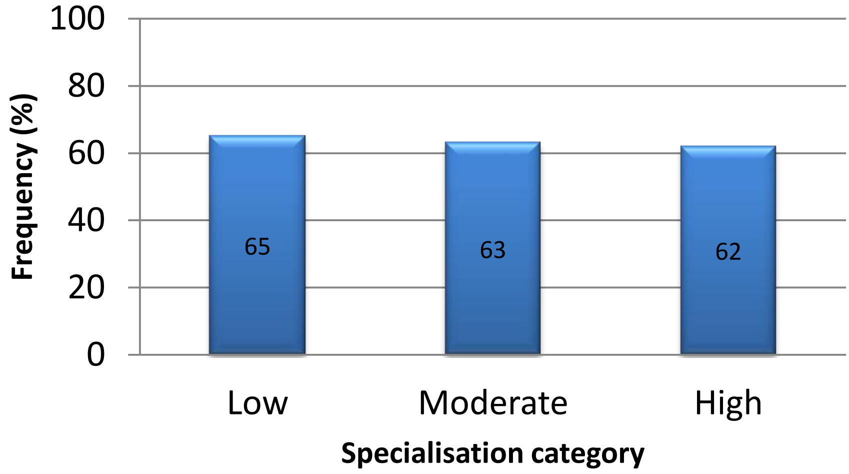

Figure 4.3. Relative frequencies of children reporting a history of 'acute injury'.

This lack of significant association was confirmed using logistic regression analyses. Both univariate and multiple logistic regression models were created, and even when adjusting for confounding variables (school size, gender and decile) and participation volume, it was confirmed there was no significant relationship between 'acute injury' and specialisation category (see Table 4.7). A summary of the predictive strength of the multiple logistic regression model examining this association can be found in Appendix G, Table G1.

Table 4.7 *Association between 'acute injury' and specialisation.*

Specialisation category	**Unadjusted* OR (95% CI)**	***p* Value**	**Adjusted OR** (95% CI)**	***p* Value**
Low	-		-	
Moderate	0.95 (0.69–1.30)[a]	0.73	0.88 (0.64–1.22)[a]	0.45
High	0.89 (0.62–1.28)[a]	0.53	0.84 (0.58–1.22)[a]	0.36

OR, odds ratio. *Univariate logistic regression analysis. **Multiple logistic regression analysis model controlled for participation volume (in hours/week), school size (categorical), gender, and decile (categorical). [a] The reference group for analysis was the low specialisation group.

4.2.4 Section summary.

After adjusting for confounding variables, there was no significantly increased odds of reporting a history of 'any injury' or an 'acute injury' by athletes in the moderate or high specialisation groups, compared with the low specialisation group. Being moderately specialised significantly increased the odds of reporting a history of a 'gradual onset injury' in the previous 12 months compared with being highly specialised.

4.3 Association between Organised Sport Volume and Injury

This section reports the results of statistical analyses completed to examine the association between various organised sport volume measures and different injury types. The section is separated into four parts, each reporting on a specific volume measurement, including previously reported 'thresholds' surrounding safe participation levels. These thresholds include not exceeding hours per week based on age in years, not exceeding a 2:1 ratio of organised sport to free-play activity, and not playing any one sport for more than 8 months of the year.

4.3.1 Association between average weekly volume (hours) and injury.

An increase in average weekly volume was significantly associated with increased odds of a child reporting 'any injury' (adjusted OR = 1.07) or a 'gradual onset injury' (adjusted OR = 1.09), but not an 'acute injury'. The odds ratios from the univariate and multivariate logistic regression analyses for each injury type are reported in Table 4.8. A summary of the predictive strength of the multiple logistic regression models examining these associations can be found in Appendix G, table G2.

Table 4.8 *Association between history of injury and average weekly sport participation volume (hours).*

Injury type	**Unadjusted*** **OR (95%CI)**	***p* value**	**Adjusted**** **OR (95%CI)**	***p* value**
Any injury	**1.08 (1.03–1.13)**	**<0.01**	**1.07 (1.02–1.12)[a]**	**<0.01**
Gradual onset injury	**1.10 (1.05–1.14)**	**<0.01**	**1.09 (1.05–1.14)[b]**	**<0.01**
Acute injury	1.02 (0.98–1.06)	0.30	1.01 (0.97–1.05)[c]	0.70

OR, odds ratio. $p < 0.05$ is statistically significant **(Bold font).** * Univariate logistic regression. **Multiple logistic regression. [a] Model controlled for decile (categorical), school size (categorical) and specialisation category. [b] Model controlled for age (categorical), school size (categorical) and specialisation category. [c] Model controlled for decile (categorical), school size (categorical), gender and specialisation category.

4.3.2 Association between sport participation in one sport for more than 8 months of the year and injury.

Participation in one sport for more than 8 months of the year was associated with significantly higher odds of reporting 'any injury' and a 'gradual onset injury' (see Table 4.9). The relative frequencies of each group reporting an injury history is shown in Figure 4.4. Whilst univariate regression analysis demonstrated an association between playing one sport for more than 8 months of the year and a history of 'acute injury', the association became statistically non-significant when the confounding variables (gender, school size and decile) were controlled for. A summary of the predictive strength of the multiple logistic regression models examining these associations can be found in Appendix G, Table G3.

Table 4.9 *Association between reporting a history of injury based on playing one sport for more than 8 months of the year*

Injury type	**Unadjusted*** **OR (95%CI)**	***p* value**	**Adjusted**** **OR (95%CI)**	***p* value**
Any injury	**1.73 (1.23–2.24)**	**<0.01**	**1.56 (1.10–2.20)[a]**	**0.01**
Gradual onset injury	**1.72 (1.17–2.54)**	**0.01**	**1.60 (1.07–2.36)[b]**	**0.02**
Acute injury	**1.44 (1.05–1.97)**	**0.03**	1.33 (0.96–1.83)[c]	0.09

OR, odds ratio. $p < 0.05$ is statistically significant **(Bold font).** * Univariate logistic regression. **Multiple logistic regression. [a] Model controlled for decile (categorical), school size (categorical). [b] Model controlled for age (categorical), school size (categorical). [c] Model controlled for decile (categorical), school size (categorical), and gender.

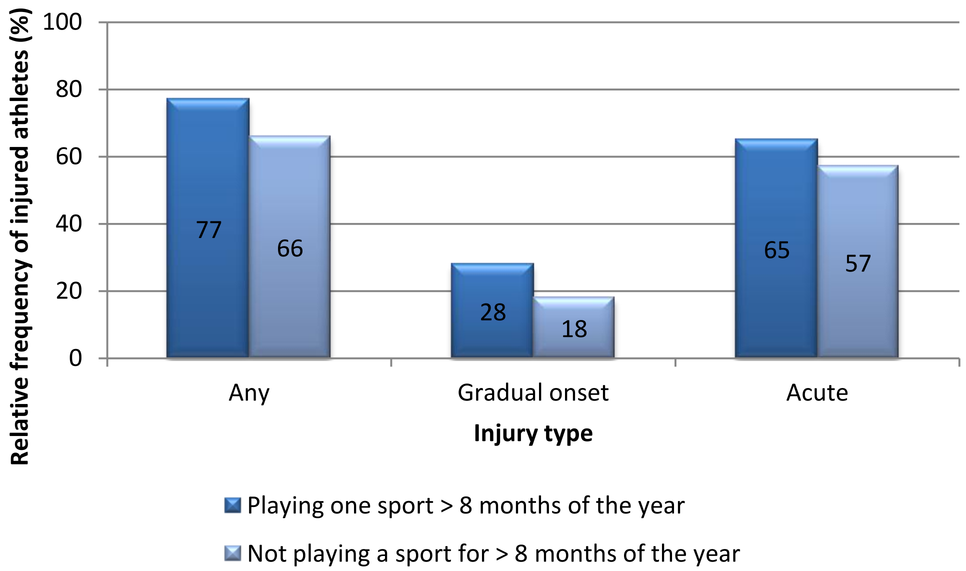

Figure 4.4. Relative frequencies of children reporting an injury (by type) when participating for >8 months or <8 months in one sport/year.

4.3.3 Association between exceeding hours per week based on age in years and injury.

Children participating in more weekly hours of organised sport than their age in years had significantly higher odds (adjusted OR = 2.42) of reporting a history of 'gradual onset injury' compared with those who did not exceed this volume recommendation (see Figure 4.5; Table 4.10). However, there was no statistically significant association between exceeding this volume recommendation and reporting 'any injury' or an 'acute injury'. Figure 4.5 shows the relative frequencies of injured children who did and did not exceed this recommendation.

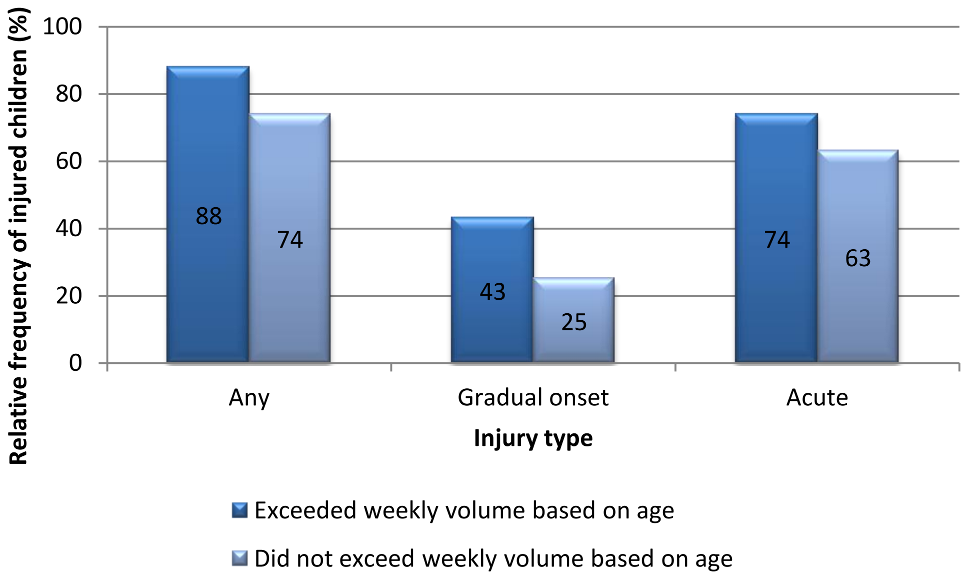

Figure 4.5. Relative frequencies of injured children who did and did not exceed weekly volume recommendation based on age.

Table 4.10 reports the unadjusted and adjusted odds ratios and 95% confidence intervals calculated from the logistic regression analyses of the associations between each injury type and exceeding this threshold. A summary of the predictive strength of the multiple logistic regression models examining these associations can be found in Appendix G, Table G4.

Table 4.10 *Association between participation in more weekly organised sport than years in age and injury history.*

Injury type	**Unadjusted[*] OR (95%CI)**	***p* value**	**Adjusted[**] OR (95%CI)**	***p* value**
Any injury	**2.64 (1.02–6.79)**	**0.05**	2.47 (0.95–6.42)[a]	0.06
Gradual onset injury	**2.28 (1.21–4.28)**	**0.01**	**2.42 (1.27–4.62)[b]**	**0.01**
Acute injury	1.67 (0.83–3.36)	0.15	1.52 (0.75–3.08)[c]	0.25

OR, odds ratio. $p < 0.05$ is statistically significant **(Bold font).** [*] Univariate logistic regression. [**]Multiple logistic regression. [a] Model controlled for degree of specialisation, decile (categorical), school size (categorical). [b] Model controlled for degree of specialisation, age (categorical), school size (categorical). [c] Model controlled for degree of specialisation, decile (categorical), school size (categorical), and gender.

4.3.4 Association between exceeding a ratio of 2:1 of weekly organised sport participation hours to weekly free-play hours and injury.

Children who participated in more than twice as much organised sport hours per week than free-play activity, had significantly higher odds (adjusted OR = 1.52) of reporting a history of a 'gradual onset injury' than children who did not exceed this ratio (Table 4.11).

Table 4.11 *Association between playing more than twice the hours of weekly organised sport to free-play activity and reporting an injury.*

Injury type	**Unadjusted*** **OR (95%CI)**	***p* value^**	**Adjusted**** **OR (95%CI)**	***p* value^**
Any injury	1.15 (0.81–1.64)	0.44	1.12 (0.78–1.60)[a]	0.55
Gradual onset injury	**1.51 (1.07–2.11)**	**0.02**	**1.52 (1.08–2.15)[b]**	**0.02**
Acute injury	0.94 (0.68–1.29)	0.69	0.92 (0.67–1.27)[c]	0.62

^ $p < 0.05$ is significant **(Bold font)** * Univariate logistic regression, **Multiple logistic regression. [a] Model controlled for decile (categorical) and school size (categorical). [b] Model controlled for degree of specialisation and school size (categorical). [c] Model controlled for decile (categorical) and school size (categorical).

In contrast, there were no statistically significant associations between exceeding this 2:1 ratio and reporting 'any injury' or an 'acute injury' history. Figure 4.6 shows the relative frequencies of injury for each of these groups.

Because this analysis was based on a subset of the total population (n=793), separate analyses between each injury type and potential confounding variables were carried out in order to determine which variables to control for in the multiple logistic regression analyses. The results of this additional analysis are shown in appendix F, Table F5.

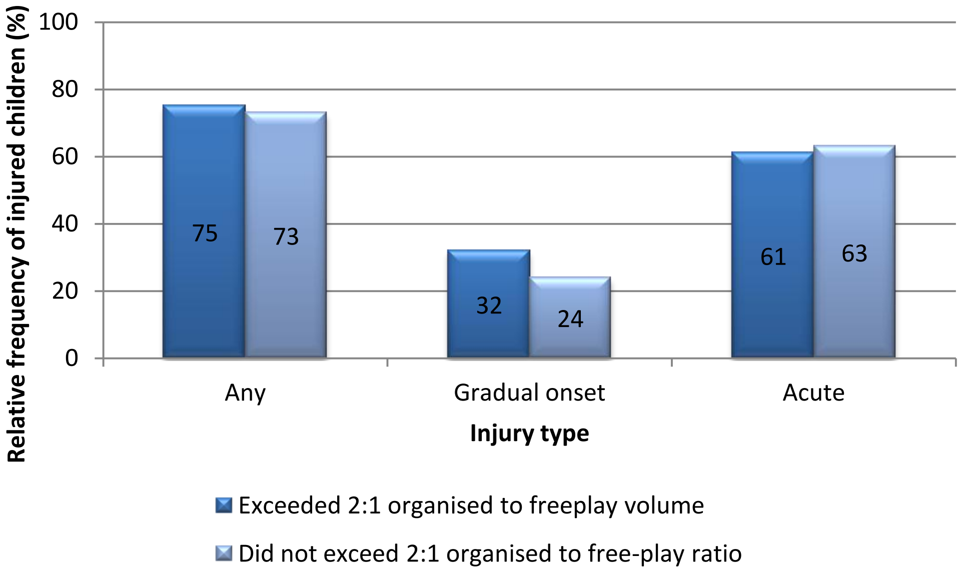

Figure 4.6. Relative frequencies of injured children who did and did not exceed a 2:1 weekly ratio of organised sport to free-play.

A summary of the predictive strength of the multiple logistic regression models examining these associations can be found in Appendix G, Table G5.

4.3.5 Section summary.

There was a statistically significant association, after adjusted for confounding variables, between the average weekly volume of organised sport participation and reporting a history of 'any injury' or a 'gradual onset injury' in our sample population of 10–13-year-old children. There were also statistically significant associations between exceeding all three of the tested volume recommendations and reporting a 'gradual onset injury', after adjusting for confounding variables. In contrast, there was no significant association between any of these volume thresholds and reporting an 'acute injury'. Thus, children who exceeded the recommended volume thresholds had significantly higher odds of reporting a history 'gradual onset injury'.

Chapter 5: Discussion

Introduction

This chapter summarises and examines the main findings from this study, and explores the significance of the results in relation to the current literature on the topic. In keeping with the research questions and presentation of the results, the findings will be discussed in the following sections: specialisation, participation volume, participant and injury characteristics, and sport-specific trends. Limitations of this study will be acknowledged and recommendations for future research, as well as the practical implications of this study, will be presented.

5.1 Specialisation

Despite having younger participants (aged 10–13 years), the prevalence of highly specialised children in our study (25%) is within the range reported by other studies also rating specialisation on a three-point scale (13%–38%), (Bell et al., 2016; Jayanthi et al., 2015; McGuine et al., 2017; Pasulka et al., 2017; Post, Bell, et al., 2017; Post, Trigsted, et al., 2017). Given the younger age of our participants, it was hypothesised that fewer children would be rated as highly specialised compared with other studies in which participants' ages ranged between 8 and 18 years. Both Jayanthi et al. (2011) and Post, Thein-Nissenbaum, et al. (2017) noted in their studies that as participants' age increased, so did the degree of specialisation. Others noted a peak in high specialisation in their participants occurring at around age 15 (Bell et al., 2016; Post, Trigsted, et al., 2017). Thus, when comparing our results to previous studies, it would appear that the prevalence of highly specialised pre- and early adolescent NZ children may be considered high given the age range. The range in prevalence of highly specialised athletes from previous studies is quite substantial and this discrepancy requires exploring to understand how our results compare. It is interesting that the highest (38%; Post, Trigsted, et al., 2017) and lowest (13%; McGuine et al., 2017) previously reported prevalence's of highly specialised athletes were both sourced from non-clinical environments in the same geographical region (Wisconsin, USA). The authors of the study reporting a prevalence of only 13% suggested that their much lower observed rate could be attributed to their sample containing a relatively large percentage (17%) of American football players (McGuine et al., 2017). This inclusion, they explained, may have skewed their data as the opportunities to specialise in American football in the state of Wisconsin are limited owing to a short competition season and limited "out of season" participation options. By contrast, in the study at the upper end of the range (37.5%), American football players represented only 5% of the sample (Post, Trigsted, et al., 2017); this could explain the difference in the reported prevalence of highly specialised athletes. The fact that different sports may demonstrate different specialisation patterns has been reported elsewhere (Pasulka et al., 2017; Post, Bell, et al., 2017). In the current study, many of the sports represented offer opportunities in NZ for children to participate year round, but can also be participated in seasonally (2018; *New Zealand Football Youth Framework* 2016; 2018). Therefore, it is unlikely that our reported prevalence of 25% is skewed by any one sport.

Another possible reason for the discrepancies in highly specialised prevalence among previous studies could be the measurement tool used. The three-point scale, although widely used in many studies and settings, has not been well validated (to our knowledge we are the first authors to report on the reliability of the scale). In fact, several versions of the questions have been asked and, recently, some authors have identified subsets of athletes who may have been mis-categorised (McGuine et al., 2017; Pasulka et al., 2017). Drawing upon a recommendation by Pasulka et al. (2017), the current study included an additional question: "Have you only ever trained/competed in the one sport"? This question was aimed at ensuring we captured the highly specialised athletes who had not had to withdraw from other sports to specialise, but who had always focused on one sport. This phenomenon could be common in many sports with the introduction of multiple levels of participation (school, club, representative), even from a very young age, making it difficult for children to participate in a range of sports. In our study, 21% of the children answered 'yes' to this question, supporting the concerns that Pasulka et al. (2017) expressed when they queried if this group of early specialisers were being missed. However, it is also possible that the addition of this question could have resulted in more children being categorised as highly specialised when in fact they were only ever recreationally involved in one sport.

As other studies have highlighted, sport specialisation is better appreciated on a continuum rather than through a simple self-rated single or multi-sport option (Bell et al., 2016). Whilst the three-point scale was designed to categorise the varying degrees of specialisation, and therefore identify children who are heading towards becoming highly specialised, it is possible that it still falls short of accurately categorising the highly single-sport specialised athlete (Pasulka et al., 2017). One important component that the three-point scale fails to differentiate is the 'intensity and volume' of organised sport participation. Although the scale differentiates those athletes who play a sport year-round from those that do not, it does not identify how frequently or how intensely those athletes participate. Looking at the data from our study, we can see that even in the highly specialised group, the weekly participation hours include a lower range of 0.5 hours. Essentially, this means a child who plays a game of (for example) netball, once a week in winter and summer, does not train and does not play any other sport, is being classified as highly specialised. Contrast this with the '38 hours a week' child (the other end of the highly specialised range of weekly hours in our study), a competitive swimmer who has withdrawn from all other sports due to the commitment required from swimming, and who trains for 2 hours morning and night every day, year-round, and competes every other week in competitions. Clearly, there is a substantial difference in the two examples from this study in terms of injury risk from being a ‘single sport specialised athlete’, and yet the three-point scale cannot, on its own, differentiate between these children. It may be, therefore, that for early sport specialisation to be researched as a stand-alone risk factor for injury, the rating system will need to differentiate the frequency and intensity of the sport participation, to truly identify those who are, by definition, highly specialised. Therefore, the addition of the extra question in this study may have raised the overall percentage of NZ 10–13-year-old children who were categorised as highly specialised. Although this could be a more valid measure compared with some overseas reports, it would appear that participation intensity and volumes should be differentiated for more accurate categorisation.

Previous research, which has demonstrated that being highly specialised in any of a variety of different sports was associated with a higher rate or history of injury in youth, does not conclusively demonstrate that this association is due to *early* specialisation (Jayanthi et al., 2015; McGuine et al., 2017; Post, Trigsted, et al., 2017). In the current study, the only independent association between specialisation and injury found was that children who were moderately specialised had higher odds of reporting a 'gradual onset injury' than those who were highly specialised. Being highly or moderately specialized did not increase the odds of reporting a history of 'any injury'. This finding is contrary to previous studies, which have suggested that highly specialised athletes are more likely to sustain or report a history of 'any injury' or 'gradual onset injury' than athletes who were rated as having low specialisation (Bell et al., 2016; Jayanthi et al., 2015; McGuine et al., 2017; Post, Trigsted, et al., 2017). A possible explanation for the discrepancy between our findings and those in previous studies is the distribution of participants over the three specialisation categories. The number of children who were categorised as moderately specialised in our sample (43%) is higher than all of the previous studies reporting an association between injury and the degree of specialisation. This suggests that our sample could be considered to be made up of 'emerging specialisers'. Given the age and developmental stage of our participants, this is not surprising. It is possible that a proportion of the moderately specialised children in our study are on a specialised pathway in one sport, but are still trying to juggle secondary sports as well. While this 'diversification' is in fact what experts recommend (DiFiori et al., 2014), the overall exposure to potentially much higher participation volumes in a single sport in addition to secondary sports may increase the risk of injury, specifically a 'gradual onset injury', in our moderately specialised group. This finding warrants further investigation.

Another possible explanation for the lack of an association between high specialisation and injury in this study is that the highly specialised children in this age range could actually be physically benefiting from the specialised practice at this stage of the specialisation pathway. They may receive access to better resources and more informed coaching (in relation to technique and landing skills) in an early specialised environment, which may help refine and perfect their sport-specific skills and improve their physical condition, offering a protective effect from injury (DiStefano et al., 2010; Silder et al., 2017). This 'possible benefit' of early specialisation has been discussed elsewhere (Fabricant et al., 2016), but remains a theoretical possibility, without a strong evidence base to support it. It is therefore an important area of research that needs further investigation to provide evidence-based recommendations regarding early specialisation and injury prevention.

Furthermore, because this is the first study investigating the association between early specialisation and injury in 10–13-year-olds, our findings cannot be extrapolated to all youth. Because the results of previous studies in older children suggested that high specialisation is associated with injury, we must be cautious not to dismiss specialisation as a risk factor for injury. This study has demonstrated that there is a relatively high prevalence of moderate-to-highly specialised 10–13-year-old children in NZ. The present study also raises the possibility that *early* sport specialisation may be initially protective. What we cannot determine from this study, however, is what occurs in terms of injury after several years of specialisation. It is still possible that early specialisation is a contributing factor to the rise in youth injuries later on in an athlete's career; however, this may only become evident after several years on the specialisation pathway. Also, it should be remembered that there have been other negative consequences of early specialisation reported, besides injury, including high rates of drop out, social isolation and burnout (Mostafavifar et al., 2013). Therefore, despite the lack of association with injury identified in this study, early sport specialisation should still be approached with caution. Further work is required to first establish the validity of the specialisation rating system, and for prospective studies to specifically investigate and follow injury outcomes in 10–13-year-old children with various degrees of specialisation. Finally, readers should be aware that differences in findings between our study and previous studies may be due to differences in methodology, such as the methods used for rating specialisation, and differences in the analyses performed, with many previous studies failing to adjust for confounding variables such as participation volume.

5.2 Participation Volume

The positive association found in this study between weekly organised sport participation volume and 'any injury' or 'gradual onset injury' supports the findings of several similar overseas studies (Jayanthi et al., 2015; Kahlenberg et al., 2016; Post, Bell, et al., 2017; Visnes & Bahr, 2013). In this study, we found that for every extra hour of weekly organised sport participation a child had 1.09 times the odds of reporting a 'gradual onset' injury, and 1.07 times the odds of reporting 'any' injury. This association seems relatively small; however, we can interpret these odds ratios better if we use a practical scenario. For example, a child selected for a representative team would likely increase their participation by one or two practices per week and one game per week (approximately 5 hours extra participation). This child would therefore have 1.4 times greater odds of reporting a history of 'any injury' and 1.5 times greater odds of reporting a history of 'gradual onset injury' based on our results. When viewed in this way, it can be seen that, with the addition of one extra team to play for, there is a substantial increase in the odds of reporting a history of 'any injury' or 'gradual onset injury'.

In the present study, we tested three of the four volume thresholds that have been previously reported (Cuff et al., 2010; Jayanthi et al., 2015; Olsen et al., 2006; Post, Trigsted, et al., 2017) and recommended in youth sport participation guidelines (Brenner et al., 2016; DiFiori et al., 2014; LaPrade et al., 2016; McLeod et al., 2011). The question of ‘how much is too much’, in regards to participation volume in youth organised sport, has been frequently asked in recent literature (Biber & Gregory, 2010; Feeley et al., 2016; Reider, 2017; Whatman, 2015). The most common guideline given to parents and children suggests that a youth athlete should not participate in any more hours of organised sport per week than their age in years. In contrast to some other studies, our results indicate that very few of the children in the 10–13-year age range (5%) exceeded this weekly volume threshold. This is low compared with the 25 to 49% of children reportedly exceeding this threshold in previous studies (Jayanthi et al., 2015; Post, Trigsted, et al., 2017). Whilst this appears to be a positive finding, indicating that most of the children in our study were participating in less sport than the recommended weekly maximum, the total number of injuries reported was very high. In analysing the association between exceeding this weekly volume and reporting an injury, our results confirm there were significantly higher odds (OR = 2.42) of reporting a history of 'gradual onset injury' if a child participated in more hours of sport per week than their chronological age. Also, although just outside of statistical significance (p = 0.06), the adjusted odds for sustaining 'any injury' when exceeding this volume were also suggestive of an association (OR = 2.47). It may be, therefore, that in the 10–13-year age range (when many experience the adolescent growth spurt), the age-based weekly volume threshold could actually be too high to use as a safety level. In the study by Purnell et al. (2010), the weekly number of hours where injury risk significantly increased in their 11–13 year-old acrobatic gymnasts, was much lower than the athletes chronological ages (for example, exceeding 8 hours per week at age 11 years). Whilst their results are by no means transferable to all sports, another large study (*N* = 2850) reported significantly higher odds (OR = 4.41) of 14–19-year-olds reporting a sport-related injury in the past year based on participation volumes much lower than their chronological age (7–10 hours per week) (Rose, Emery, & Meeuwisse, 2008). That said, our results further support the results reported by Jayanthi et al. (2015) and Post, Trigsted, et al. (2017), which demonstrated significantly higher odds of reporting a 'gradual onset injury' if the average weekly participation volume was in excess of the child's chronological age, even when controlling for all confounding variables.

Our findings also support the established association between playing one sport for more than 8 months of a year and injury (Bell et al., 2016; Cuff et al., 2010; Olsen et al., 2006; Post, Trigsted, et al., 2017). A positive association was seen between exceeding this volume and sustaining an injury in all three injury categories that we analysed. However, the association with 'acute injury' was not statistically significant when controlling for confounding variables (school size, gender and decile). Consistent with the previous literature, a child in the current study had increased odds of reporting 'any injury' and ‘gradual onset injury’ in the past 12 months, if they had played one sport for more than 8 months of the year. In previous decades, most youth sport in NZ was typically seasonal, and it was common for young athletes to play different 'winter' and 'summer' sports that were often quite unique in terms of movement demands (Sam, 2007; SPARC, 2003). However, many traditionally seasonal sports are now crossing over multiple seasons. An example of this change was illustrated by Higham and Hinch (2002) showing that in 1975 the NZ rugby season started in late May and finished in mid-September, compared with 1999, where the season began in January, and continued until October. Although this illustration was from senior competition levels, the effects of these evolutions have trickled down to the youth sport environment. Most traditionally 'winter' sports now have a summer youth programme available, or have simply extended their seasons into summer months (Basketball New Zealand, 2018; North Harbour Hockey, 2018; Northern Football Federation, n.d).

In regards to injury prevention research, many authors have commented that inadequate rest periods from sport and consequential fatigue, can be a significant contributing factor for sport-related injury in children (Bergeron, 2009; Jayanthi & Dugas, 2017; Luke et al., 2011; McLeod et al., 2011). While the ideal rest period has not been determined, Jayanthi and Dugas (2017) have suggested that at least a month's rest from organised sport at the end of a sport season is recommended whereas McLeod et al. (2011) suggest that 1–2 days per week of rest from organised sport is required for children. Brenner (2007), on the other hand, suggests weekly rest of 1–2 days as well as longer breaks every 2–3 months as a sensible rest programme for young adolescent athletes. A further study demonstrated that adolescents who played sport over all four seasons of the year without a break were significantly more likely to sustain an overuse injury than those who played in three or fewer seasons of the year (Cuff et al., 2010). Approximately three quarters of the children in our study participated in one sport for more than 8 months of the year. Thus, it can be concluded that the majority of NZ 10–13-year-olds are participating in sports that do not fit into the traditional winter or summer season. What we cannot determine, however, is how frequent or intensive that participation was. Acknowledging these limitations our findings further support the recommendation that children should not participate in one sport for more than 8 months of the year.

The final volume-based threshold we investigated was the ratio of organised sport to free-play activity. We found that a child who spent twice as much time or more in organised weekly sport as they spent doing 'free-play' activity had significantly higher odds of reporting a history of 'gradual onset injury', even when controlling for confounding variables. In contrast, there was no significant association found between exceeding this ratio and a history of sustaining 'any injury' or an 'acute injury'. This finding is similar to that of Jayanthi et al. (2015), who demonstrated a significant association between exceeding a 2:1 ratio of organised sport to free-play and sustaining a serious overuse injury. These results raise a potentially important idea, because essentially these findings could infer that free-play activity offers a protective effect from 'gradual onset injury' in children who participate in organised sport. What differentiates free-play activity from organised sport practices and competitions is the lack of adult direction (Barreiro & Howard, 2017; Ford & Williams, 2017). The unstructured nature of free-play is inherently familiar to many earlier generations, where childhood was filled with self-driven physical play, whether it be bike riding or kicking a ball around with a friend. In modern NZ society, it has become significantly less common to see children gather to 'play in the park or street' (Duncan & McPhee, 2015). Overseas data have shown a 25% reduction in free-play activity over the past 20 years (Barreiro & Howard, 2017) and this seems to be corroborated by a recent investigation into NZ children's play habits (Duncan & McPhee, 2015). According to the 2016 'State of play' survey, 72% of children <18 years of age do not climb trees often, 54% do not ride bikes often, and 85% of 8–12-year-olds do not roam in their neighborhood unsupervised by an adult (Duncan & McPhee, 2015). This reduction in free-play activity is explained by many societal changes, including the increase in screen/device use in children, the concern of harm coming to unsupervised children, and possibly, the lack of spare time due to an increase in organised sport commitments (Barreiro & Howard, 2017; Duncan & McPhee, 2015; Walker & Haughey, 2012).

The holistic benefits of unstructured free-play have been reported as improvements to creativity, adaptability, decision-making skills, and physical flexibility (Baker et al., 2003; Coutinho et al., 2016; Memmert et al., 2010). Other benefits of free-play include improvements in social skills, conflict resolution, risk-management and self-regulation of when enough is enough (Barreiro & Howard, 2017; Duncan & McPhee, 2015). From an injury perspective, this is perhaps why the children who partake in adequate ratios of free-play to organised sport reported fewer gradual onset injuries than those who participated in minimal weekly free-play relative to the amount of organised sport. During an organised training session, or a competition, a child is less likely to stop if they feel fatigued or slightly sore. Whereas in a free-play environment, they learn to stop playing when tired or hurt. Equally, the improved flexibility, adaptability and decision-making skills gained from the free-play environment may have provided some kind of intrinsic injury protection against gradual onset conditions for the children who regularly engaged in weekly free-play as well as organised sport.

5.3 Participant and Injury Characteristics

The current study is the first to have examined the effects of specialisation and participation volume solely on early adolescent-aged children. Previous studies have included much broader age ranges, spanning 8–18 years (Jayanthi et al., 2015; McGuine et al., 2017; Pasulka et al., 2017; Post, Trigsted, et al., 2017). While a broader age range may offer insight into the trends of sport participation throughout adolescence, the results have not answered questions specifically surrounding the implications of early sport specialisation, which by definition only include children younger than 13 years of age (Côté et al., 2012; LaPrade et al., 2016). Also, the effects of high organised sport participation volumes through the period of rapid skeletal growth known as the adolescent growth spurt can only be determined when looking at those age-specific groups. While there is considerable variation in chronological age for peak skeletal growth, it is most common for it to occur between 11 and 13.5 years of age (Hauspie, Bielicki, & Koniarek, 1991; Sanders et al., 2017).

The mean age (±SD) of the children in our sample was 12.6 ±0.5 years (range 10.8–13.9). This is distinctly different to previous research where the average age of participants ranged from 13.4 to 18.6 years. The closest previously studied age ranges to the current study investigating injury risk factors were those from Junge et al. (2016) who looked at 8–15-year-olds and Boström et al. (2016) who investigated 11–15-year-olds. Interestingly, neither of these studies reported any significant associations between overall sport volume and injury, and neither investigated specialisation. The children in our sample were primarily under the age considered to define early specialisation (Côté et al., 2012; LaPrade et al., 2016). This means the results obtained from this data contribute more specifically to the debate regarding the effects of *early* sport specialisation. Likewise, the chronological age range of participants in our study is very similar to that of the peak growth age mentioned above. Thus, the discussion on the association between participation in a high volume of sport, during a period when rapid skeletal growth is most common, and injury, can be better related to the current study's data set.

Children are more likely to sustain gradual onset injuries during the adolescent growth spurt (DiFiori et al., 2014), and could also be more at risk of acute injuries during this growth owing to biomechanical faults (Beese et al., 2015; Jayanthi et al., 2013; Stull, Philippon, & Laprade, 2011). The percentage of injured children in the current study (74%) is much higher than the percentages reported in similar overseas studies (49%–51%), which also measured injuries retrospectively over a 12-month period (Boström et al., 2016; Cuff et al., 2010; Post, Trigsted, et al., 2017). Also, in the current study, the percentage of injuries that were categorised as 'gradual onset' in nature (22%) was lower than those reported in many similar retrospective overseas studies (35%–67%) (Cuff et al., 2010; Jayanthi et al., 2015; Post, Trigsted, et al., 2017). The relatively low percentage of 'gradual onset injuries' reported in our study is somewhat surprising, given that the children were theoretically intrinsically prone to growth-related 'gradual onset injury' owing to their age range (Sanders et al., 2017). The discrepancies between the current study and previous studies in both the overall percentage of injured participants and the percentage of gradual onset injuries, is most likely explained by the different injury definitions used in the studies. Injury definitions that include 'any pain that may result in modified or interrupted participation' (Cuff et al., 2010; Malisoux et al., 2013) have recorded more injuries in total over a year than those using a pure time-loss definition (Boström et al., 2016; Møller et al., 2017; Post, Trigsted, et al., 2017). The 'any pain' definition has also been shown to identify more gradual onset or 'overuse' injuries than a time-loss definition (Clarsen et al., 2013). In the current study, we recorded both 'time loss' and 'play through' injuries. There were 117 children who reported only 'play through' injuries, and these accounted for 13% of the total unique injuries reported in this study. Had we only used a time-loss definition, these injuries would have gone unnoticed. Of interest, however, was that only 41 of these 206 injuries were categorised as gradual onset injuries. The remaining 80% of the ‘play through’ injuries in the children that only reported this type of injury, were acute. Thus, the current study’s definition of a 'play through' injury has also led to more acute injuries being reported. It could be that these were all 'minor' injuries (e.g., a twinge of an ankle, but able to play on); however, it may also indicate that children are 'playing on' in their sport, despite sustaining an injury. This idea that many early adolescent children may be 'playing on' despite sustaining injury warrants further investigation, as it was recently reported that up to 87% of secondary school children admitted to hiding an injury in order to continue playing sport (Whatman et al., 2018).

Another possible explanation for the relative proportion of injury types in the current study is that, in contrast to many studies, children were surveyed without parental help. We were asking children aged 10–13 years to retrospectively recall injuries that occurred in the last 12 months. Acknowledging that children needed to understand the concept of 'gradual onset injury', we carefully worded questions to ask them if they had suffered 'any injury' that they were able to keep participating with, hoping that this would result in the children reporting growth-related gradual onset injuries that affected their participation but did not result in them stopping playing. Every child who recalled 'any injury', was individually interviewed by a research assistant in an attempt to accurately categorise each injury. While this may have ensured that those who did recall an injury were accurately categorised as acute or gradual onset, it would unfortunately not reduce the children who simply did not report pain that affected their participation. It is therefore possible that the current study has underestimated growth-related gradual onset conditions given that the 'pains' these cause may not have been considered as 'an injury' by the child.

5.5 Sport Specific Trends

In the current study, there were large variations in the number of participants represented in each sport group, and so comparative between-group analyses regarding specialisation and participation volumes in each sport were not possible. Therefore, only the descriptive statistics regarding the main sports identified for the moderately and highly specialised children are discussed.

The two sports with the highest relative frequencies of highly specialised children in our sample were gymnastics (50%) and tennis (44%). This finding is consistent with those of Pasulka et al. (2017) for whom tennis (47%) and gymnastics (30%) were also the sports with the highest proportion of highly specialised athletes. They also reported that their gymnasts had the youngest average age for specialising (mean = 8.9 years) out of all the sports represented (Pasulka et al., 2017). Gymnastics has been singled out as a known 'early entry sport' (DiFiori et al., 2014), in which specialised participation from a young age is commonly required to develop the necessary skill set to progress and an immature musculoskeletal system is advantageous (Feeley et al., 2016; M. Smith, 2015). Surprisingly, out of all the team sports in our sample, basketball had the highest relative frequency of highly specialised athletes (44%). This is contradictory to studies from overseas suggesting that football (soccer) (McGuine et al., 2017; Post, Trigsted, et al., 2017) or volleyball (Pasulka et al., 2017) have the highest proportion of specialised athletes. Also, Pasulka et al. (2017) demonstrated that basketball players were on average much older when they specialised compared with soccer and volleyball players. This highlights how sport practices may differ in different countries. In 2012 in NZ, it was estimated that basketball was being played by 82,000 (69%) and 72,000 (63%) of 11–14-year-old boys and girls, respectively (Walker & Haughey, 2012). NZ also have a team represented in the Australian basketball league (NZ Breakers), which has high media coverage and so basketball is thus a professional pathway clearly visible to young children. It has been suggested that media coverage can influence children, and their parents, in pursuing a sport in a specialised capacity (M. Smith, 2015).

The average weekly participation hours for children who rated as moderately or highly specialised demonstrated gymnastics to have the highest median weekly volume (13.1 hours) when averaged out over the full year, as well as by winter (17 hours) and summer (12 hours) seasons. This is unsurprising, as gymnasts are known to train at a high volume, and the figures from the current study (median = 13.1 hours) are similar to previously reported weekly hours in gymnastics (mean = 14.6) (Pasulka et al., 2017). Interestingly however, the basketball athletes in our study had a much lower average weekly participation volume (median = 4.5 hours) than the participants in the Pasulka et al. (2017) study (12.1 hours). This was also true for all the other sports that were comparable between our study and the study by Pasulka et al. (2017), including tennis (8.5 hours vs. 12.8 hours), soccer (4 hours vs. 7.3 hours), and swimming (7.5 hours vs. 11.6 hours). This observed difference is most likely due to the variation in the age of our participants (10–13 years; average 12.6 years) compared with those in the Pasulka et al. (2017) study (7–18 years; average 14.3 years), because a linear relationship exists between increasing age and increasing sport volume (Boström et al., 2016).

The average injury frequency per specialised child, when analysed in sport groups, demonstrates gymnastics to have the highest reported frequency of 'any injury'. However, with such a small sample of gymnasts (*n*=6), caution must be applied and the results cannot be directly compared with those for other sports represented by much larger groups. Overall, moderately to highly specialised athletes in popular NZ team sports such as rugby, netball, football and hockey, had relatively low rates of reported injuries (<2 per athlete in the previous 12 months). This once again must be viewed with caution, because this average was obtained by looking at the total injuries reported by the children who were moderately or highly specialised in the named sport, divided by the number of children. It does not, therefore, represent a 'rate of injury' for all the children who participated in that sport in the previous 12 months. These sport-specific findings, while purely descriptive, may help us to understand which sports are trending towards early specialisation pathways in NZ, and could thus provide a starting platform for future research.

5.6 Limitations

This study used a retrospective design, and therefore, we have been able to look at associations between variables, but causation cannot be determined. The retrospective design represented a practical approach to data collection within the constraints of the timeframe of this study. The NZ AIMS games provided an environment rich in children in the age range where the adolescent growth spurt is most common. It was this age group that was targeted specifically to answer questions pertaining to early specialisation and intense sport participation volumes. To conduct a prospective study on a similar population would require significantly more resources. While modern technology would allow on-line versions of a survey to be distributed weekly for an injury surveillance study, non-response bias is a common problem with this method (Schofield & Knauss, 2010).

Another potential limitation is that our study participants are children, and therefore, all the information provided for this study was based on the ability of each child to comprehend the questions and report accurately. In order to try and address potential recall bias we designed the survey to aid recall (weekly diary) and we provided face-to-face research assistants to assist with any questions the child may have had regarding their understanding of the questions. We also provided trained research assistants to interview every child on a 1:1 basis who reported the health outcome of interest (injury). This was implemented to improve the accuracy of sport-related injury reporting, and appropriate coding of each injury into the relevant injury category, and thus, the validity of our results. Every questionnaire was checked by a research assistant at the time of completion to ensure all answers had been provided. This ensured we had a high rate of fully completed questionnaires. We also conducted a small test-retest reliability study for the four specialisation questions, which confirmed that children in the age range of this study could reliably answer these questions.

One specific question relating to recreational play was not answered by 121/914 (13%) of participants. This may be because the child did not understand the question, or it may be that they missed it by accident due to its position at the bottom of the questionnaire. These non-responses would have affected the final volume analysis, which looked at the ratio of free-play to organised sport. In order to remove this non-response bias, a separate sub-group was formed, solely for the purpose of this analysis.

Unfortunately, the sport that each child was participating in at the NZ AIMS games was not requested. Equally, we did not ask the child to name their main sport when they identified that they could choose a main sport in question 5 (see survey, Appendix B). The way in which we identified the main sport, was through the sport diary they provided in question 9 of the survey. The sport with the most weekly hours, was considered as the main sport. This is not as accurate as the child naming the sport themselves. Therefore, the sport-specific data should be interpreted with caution. Due to this, and because some sport groups were very small, we did not perform any inferential statistics to investigate associations between individual specialised sports and injury.

The specialisation scale used in this study has not been validated. Although it has been used in many settings internationally, there remains controversy over the accuracy of the categorisations (A. Smith et al., 2017). We used this scale in a clinical pilot study, and found it was accurate in categorising highly specialised athletes (Whatman, Walters, Schluter, McGowan, & Knight, 2017); however, we cannot be sure this translates into the non-clinical environment. The data from the current study suggest that some children who have been categorised as specialised may be low risk based on their overall participation volumes. Because the scale does not require an intensity of participation rating, it is possible that children who only play one sport, year-round, but for recreation only, have been included in the highly specialised analysis. We did, however, attempt to control for participation volume when conducting the multiple logistic regression analyses on specialisation and injury associations, by forced inclusion of this variable in the model.

5.6 Recommendations

5.6.1 Injury prevention.

Based on the results from this study, we support the following volume-based recommendations in regards to injury prevention in youth sport:

1. Children should not participate in a single sport for more than 8 months of the year;
2. Children should not participate in more organised sport hours each week, than their age in years;
3. Children are encouraged to participate in regular free-play, ideally at least half as much per week as they spend participating in organised sport;
4. Parents should be aware that, for every additional hour of organised sport participation per week, the odds of reporting an injury increase.

5.6.2 Further research.

The lack of association found between early specialisation and injury in our sample of 10–13-year-old children should be investigated prospectively. A suggestion would be to recruit a group of highly specialised children and an age-matched group of children who participate in equal volumes over multiple sports. Following these children through the 10–13-year ages, and prospectively recording injuries is worthy of investigation.

The term 'early specialisation' needs to be confirmed by more studies on specialisation being conducted in the currently accepted 'early' phase of adolescence. Based on previous research, and the results from our study, clarity is needed as to the value or detriment of early specialisation. This can only be determined from prospective, longitudinal studies on the relevant age range.

The three-point scale currently being used to categorise specialisation needs to be validated for clinical and non-clinical populations. Because the accepted definition of specialisation is "intensive participation in one sport, year-round, at the exclusion of other sports", we must ensure the scale is categorising highly specialised athletes correctly. Perhaps having an additional question that qualifies how much participation occurs each week would help. For example "on average, how many trainings or competitions do you participate in for your main sport each week?", with answers being ≤1; 2-3; >3. This ensures only athletes who participate frequently (>3 participations per week) in one sport are considered highly specialised.

Chapter 6: Conclusion

6.1 Summary of Findings

The purpose of the current study was to investigate sport practice in 10–13-year-old NZ children and to determine if there was an association between either early sport specialisation or weekly organised sport participation volume and sport-related musculoskeletal injury. The investigation has shown that there was no significant association between being highly sport specialised and reporting a history of any sport-related injury. However, the prevalence of high specialisation in the current study is similar to that in previous studies on older children, suggesting that 10–13-year-old NZ children have a relatively high degree of specialisation for their age.

This research did reveal significant associations between the volume of weekly organised sport participation and reporting a history of 'any injury', and specifically, a 'gradual onset injury'. An important finding to emerge from the study was that all of the currently recommended volume thresholds, when exceeded, significantly increased the likelihood of reporting a history of 'gradual onset injury'. The volume thresholds investigated included: participating in more hours of sport per week than age in years; exceeding a 2:1 ratio of organised sport to free-play participation hours; and participation in one sport for more than 8 months of the year.

A secondary aim of this study was to analyse patterns of specialisation and participation volume in various sports. Although the number of gymnasts represented in the sample was small, out of all the sports children were specialized in, gymnastics was shown to have the highest percentage of highly specialised athletes compared with moderately specialised, the highest weekly hours of participation, and the highest frequency of reported injuries per child. Of the team sports, basketball had the highest percentage of highly specialised athletes compared with moderately specialised athletes. However, all of the team sports that were played by the moderately and highly specialised children in our sample had much lower weekly participation volumes compared with previously reported volumes.

6.2 Significance of Findings

The findings from this study make several important contributions to the current literature. Perhaps the most surprising finding to emerge is the lack of an association between high specialisation and injury. Contrary to previous research, the findings reported here suggest that early specialisation is not associated with reporting a history of sport-related injury. Based on the associations reported prior to this study, it was unclear if specialisation during the early stages of adolescence, when the musculoskeletal system is most likely undergoing peak growth, was associated with more sport-related injuries. This is the first study to examine these associations solely in 10–13-year-old children and is therefore an important contribution to the debate on early specialisation. Despite the retrospective design, the findings from the present study provide preliminary evidence that needs to be further investigated in a prospective study.

The findings of the current study's investigation into the associations between sport participation volume measures and reporting a history of injury complement those of earlier studies. These findings add to the rapidly expanding body of evidence suggesting that too much organised sport may have a negative effect on the musculoskeletal health of young adolescents. The present study has been one of the first attempts to specifically examine an age group who are vulnerable to overload injury owing to the adolescent growth spurt, as well as the first study examining these associations in NZ children. Thus, the findings from this study make a valuable contribution to our understanding of the association between the volume of sport and gradual onset injuries during early adolescence growth. Despite the retrospective design limitation, the current study adds to the evidence supporting the current volume-based recommendations for children participating in sport.

6.3 Implications of this Study

The findings from this study have several implications for clinicians working in the field of sports medicine, and for academics investigating risk factors for injury in youth sport. Physiotherapists and sport doctors in NZ have a key role in educating young athletes, parents coaches and sports administrators regarding sport volume and sport participation patterns. It is recognised that 'a one size fits all' recommendation regarding weekly volume is unlikely to result in significant injury reduction on its own; however, this study suggests that both excessive organised sport and subsequent lack of free-play increase the likelihood of reporting a 'gradual onset injury' during peak growth years. Therefore, it is recommended that clinicians working in the field of youth sport, should take the findings from this study, and together with recommendations from previous research, advise clients of the potential negative effects of participating in too much organised sport, and encourage free-play activity.

Further research is needed to continue to investigate the implications of early specialisation on the health of the musculoskeletal system of children. Prospective longitudinal studies following specialised children from pre-growth spurt to late adolescence are needed to better understand the risk of injury from early specialisation.

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Appendices

Appendix A: Ethics approval

AUT

AUTEC Secretariat

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

28 June 2017

Chris Whatman
Faculty of Health and Environmental Sciences

Dear Chris

Re Ethics Application: **17/179 Early specialisation, training volumes and musculoskeletal injury in youth athletes in New Zealand**

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 27 June 2020.

Standard Conditions of Approval

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

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

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

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

Yours sincerely,

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

Cc: jody.mcgowan@gmail.com; Simon Walters

Appendix B: Sport Participation Questionnaire

SPORT PARTICIPATION QUESTIONNAIRE

AUT

ACC SportSmart

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 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
- 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
*****see researcher for a completed example if you need help*****

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. ie Riding bikes, skateboarding, playing at the park, skiing for recreation, swimming at beach, surfing, playing on playgrounds

Hours/week

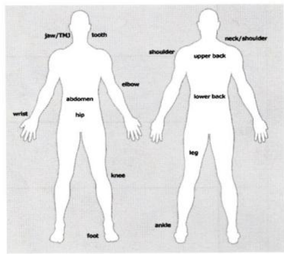
PTO

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, and take it to the researcher to discuss what type of injury it was.



13 Have you experienced any injuries while playing or practicing organised sport that you have continued to play or practice with?
- Yes → Go to Q **12**
- No → Thank-you for completing the survey.

For research assistant use only

SITE	ACUTE Contact	ACUTE non-contact	GRADUAL ONSET
1			
2			
3			
4			
5			
6			

Appendix C: Participant Information Sheet

AUT

TE WĀNANGA ARONUI O TĀMAKI MAKAU RAU

Participant Information Sheet

Date Information Sheet Produced:

7 August 2017

Project Title

Youth sport participation and injury

An Invitation

Hello. We are a group of researchers and students from AUT and we are conducting research to look at sports and injury. We are collecting information from New Zealand school students in years 7-10 who play at least one competitive sport. The information we collect will be used by a student to complete a Master's thesis. Would you like to take part in this study?

What is the purpose of this research?

The purpose of this study is to investigate how much time you spend training and competing in sport and look at the type and amount of injuries you have had. This information will help us to understand if your sport commitments influence your risk of being injured. Injuries can affect your ability to play your sport, and can cause you pain. If we can identify some ways of reducing your chance of injury, we would like to publish and present this information in a scientific journal or at a sports medicine conference. The findings we get from this study will be shared with ACC to help them prepare injury prevention guidelines.

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

You have been invited to participate in this research because you play sport at a competitive level and are between the ages of 10 and 14 years old.

How do I agree to participate in this research?

Your participation in this research is voluntary (it is your choice) and whether or not you choose to participate will neither advantage nor disadvantage you. If you choose to fill out the survey, then information you provide will be pooled with all the other survey results. We will be unable to identify individuals from the data you give. You can choose to discontinue the survey at any stage if there is a question you don't want to answer. There are research assistants here to help you if you want further explanation for one of the questions.

What will happen in this research?

To participate in this research, all you will need to do is complete the survey questions. Help is on hand to answer any questions you may want to ask. We anticipate it will take you about 5 minutes to complete this survey. Once you have filled out the survey, your participation in this research is completed. All the completed survey results will be analysed to look for associations between how much training/ sport you play and if and how many injuries, and what type, you have had in the last 12 months.

What are the discomforts and risks?

It is unlikely you will feel any discomfort by filling out this survey. There are no risks to you or your sporting career as all the survey responses are anonymous.

What are the benefits?

This research will help us understand how competitive youth sport is being practiced in New Zealand, and analyse if the amount and type of sport influences the type and amount of injuries. This information will benefit all young New Zealand athletes by informing coaches and sport medicine professionals on evidence based injury prevention strategies. Less injuries is a good thing for you, and your sport.

How will my privacy be protected?

All surveys are anonymous and confidential.

What are the costs of participating in this research?

The only cost is 5 minutes of your time.

What opportunity do I have to consider this invitation?

You can take 24 hours to consider your participation.

Will I receive feedback on the results of this research?

As the survey is anonymous, we cannot send you feedback individually. However, the results from this research will be available after July 2018 from AUT SPRINZ website by following this url:

https://sprinz.aut.ac.nz/research-bytes .

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

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 for your future reference. You are also able to contact the research team as follows:

Researcher Contact Details:

Jody McGowan, jodym@kineticsrehab.co.nz, *094245632*

Project Supervisor Contact Details:

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

Simon Walters simon.walters@aut.ac.nz 09 921 9999 ext 7022.

Approved by the Auckland University of Technology Ethics Committee on *28th June 2017*, AUTEC Reference number 17/179.

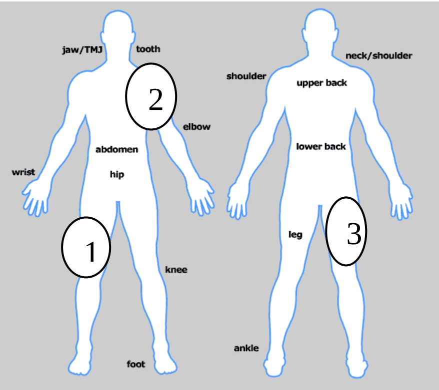
Appendix D: Injury Classification

Injury classification

For this study, we need to be able to differentiate between an ACUTE injury and an OVERUSE/GRADUAL ONSET injury. We also want to know if the injury caused the athletes to miss training or competitions. The following definitions will help, and the prompt questions will help clarify the injury type if the child is unsure of the diagnosis.

When the child brings the form to you, the body chart on page two may have one, or more circles on it. Please number each circle, and record the injury classification in the box adjacent by placing a tick under the correct heading. If you are unsure, please record a "?", and if possible write any useful information in the blank space below the box, that may aid in classification by the researcher at a later date.

See an example below.



SITE	ACUTE Contact	ACUTE non-contact	GRADUAL ONSET
1			√
2	√		
3		?	?
4			
5			
6			

Definition of an acute injury:

"An injury that occurs as the result of a **sudden event**, causing immediate symptoms".

This can be either contact or non- contact in nature. Contact involves another person, or object colliding with the injured body part. Non-contact refers to injuries that occur without contacting something, such as rolling ankle.

Definition of a gradual onset (overuse injury):

"An injury or presence of pain **not induced by a sudden event**, resulting in reduced training volume, experience of pain, difficulties participating, or reduced performance. The onset is gradual, and can be very slow, over weeks or months, or can occur over the duration of a single game or training session".

This also includes recurrent pain not occurring from a sudden event.

Questions to ask.

1. Do you know what your injury was diagnosed as?
2. Do you remember when you were injured and what happened?
3. Did it happen suddenly? OR Did it gradually get sore over time?

Potential additional questions if needed and/or time available.

4. Did your injury happen because you collided or came into contact with someone or something?
5. Did your injury occur due to a twist, overstretch, roll or strain?

Appendix E: Excel Data Entry Instructions for Research Assistants

Key for Excel entry AIMS data.

Column	Title	Response	Questionnaire number
A	Participant number	**Number**	**-**
B	Gender	**M or F**	**1**
C	Birth month/year	**i.e.: 9/2004**	**2**
D	Collection date	**9/2017**	**-**
E	School name	**i.e.: Rosmini**	**3**
F	School year	**7 or 8**	**4**
G	Age years and month	**AUTO**	**-**
H			
I	Age in numerical form	**AUTO**	**-**
J	Choose a main sport	**Y=1 N=0**	**5**
K	Play sport >8 months/year	**Y=1 N=0**	**6**
L	Only ever played one sport	**Y=1 N=0**	**7**
M	Quit all other sports	**Y=1 N=0**	**8**
N	Total score J-M	**AUTO**	**-**
O	Sport played most (only if column N =2 or 3)	**i.e.: Rugby**	**-**
P			
Q	Sum of summer only sport hours	**Number**	**9**
R	Sum of summer +all year sport hours (Q+U)	**Number**	**9**
S	Sum of winter only sport hours	**Number**	**9**
T	Sum of winter+ all year sport hours (S+U)	**Number**	**9**
U	Sum of "all year" sport hours	**Number**	**9**
V			
W	Non-organised activity hours	**Number**	**10**
X			
Y	Injury that resulted in missed time in sport	**Y or N**	**11**
Z	Number of injuries marked on body chart	**Number**	**12**
AA	Number of Acute contact injuries	**Number**	**12**
AB	Number of Acute non-contact injuries	**Number**	**12**
AC	Number of gradual onset injuries	**Number**	**12**
AD	Injury that could continue playing with	**Y or N**	**13**
AE			
AF	Hip/ upper leg	**Y or blank**	**12**
AG	Knee/ lower leg	**Y or blank**	**12**
AH	Ankle/foot/toes	**Y or blank**	**12**
AI	Spine/Torso/neck	**Y or blank**	**12**
AJ	Head/Jaw/face	**Y or blank**	**12**
AK	Shoulder/ upper arm	**Y or blank**	**12**
AL	Elbow/forearm	**Y or blank**	**12**
AM	Wrist/hand/fingers	**Y or blank**	**12**

Appendix F: Association Between Potential Confounding Variables and Injury Type

School size was found to be significantly associated with reporting a history of 'any injury' (χ^2=21.28; p<0.001), 'gradual onset injury' (χ^2=7.13; p=0.03) and 'acute injury' (χ^2=11.15; p<0.001). Figure F1 shows the between group differences in the proportions of children reporting each injury type relative to the school size they attend.

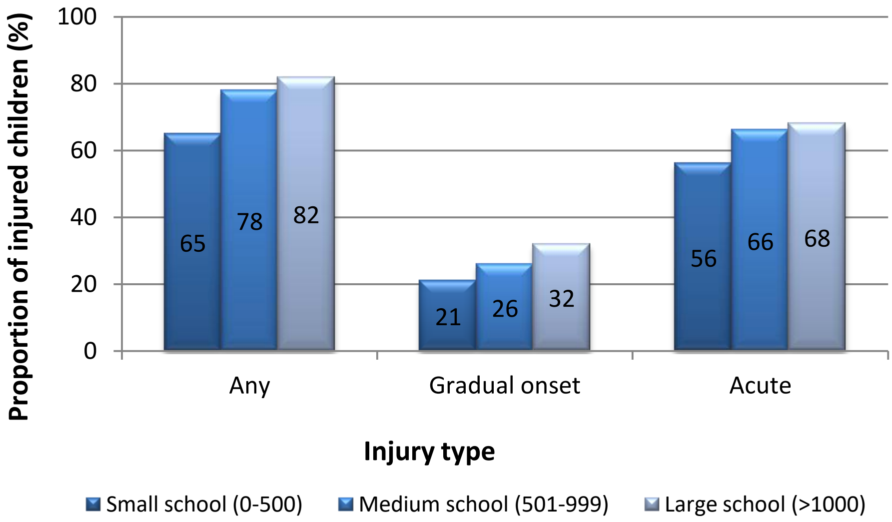


Figure F1. Proportion of injured children relative to school size.

Decile level was found to be significantly associated with reporting a history of 'any injury' (χ^2=12.79; p<0.001) or an 'acute injury' (χ^2=7.31; p=0.03), but not a 'gradual onset injury' (χ^2=3.32; p=0.19). Figure F2 shows the between group proportional differences by decile group.

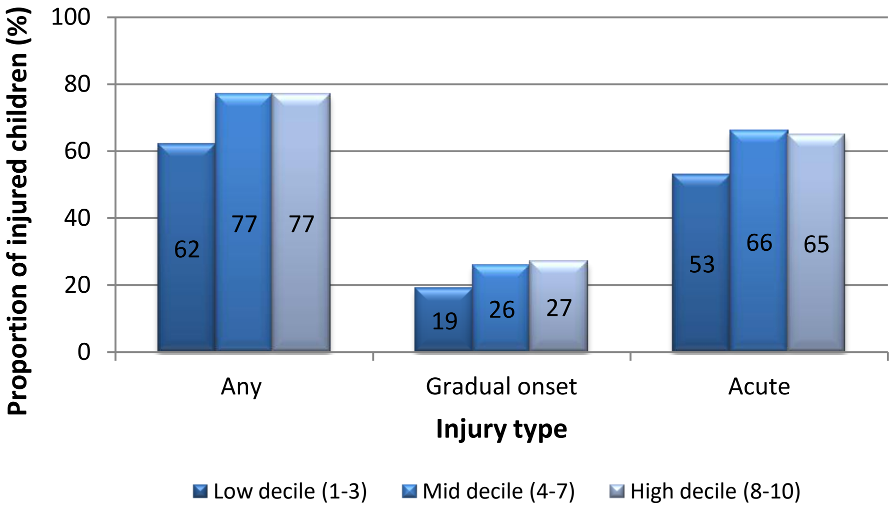


Figure F2. Proportion of injured children per decile group.

Age group was shown to be significantly associated with reporting a 'gradual onset injury' (χ^2=5.80; p=0.05) but not significant for reporting 'any injury' (χ^2=1.50; p=0.47) or an 'acute injury' (χ^2=2.54; p=0.28). Figure F3 illustrates the proportion of injured children per age group.

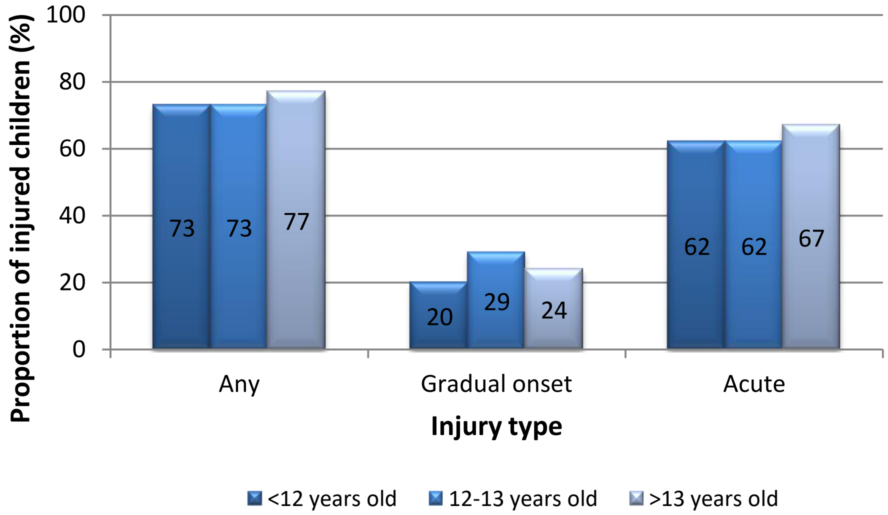


Figure F3. Proportion of injured children per age group

Gender was found to be significantly associated with reporting a history of 'acute injury' (χ^2=2.49; p=0.10), but not significant for reporting 'any injury' (χ^2=1.82; p=0.18) or a 'gradual onset injury' (χ^2=0.01; p=0.91). Figure F4 demonstrates the proportions of injured children per gender group.

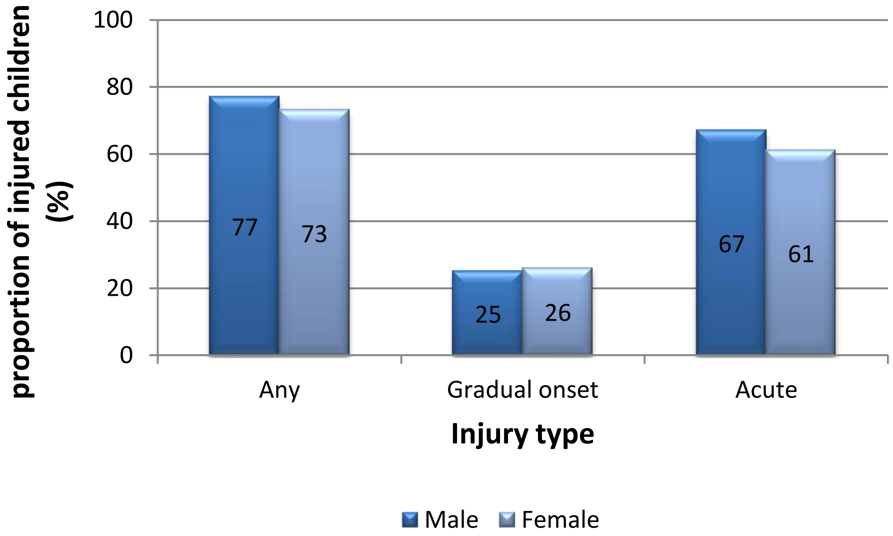


Figure F4: Proportion of injured children relative to gender.

Summary

Attending a larger school was associated with a greater likelihood of reporting a history of , 'gradual onset injury' and 'acute injury' than attending a small school. Attending a school in a high decile range was associated with a greater likelihood of reporting 'any injury' or an 'acute injury' than attending a low decile school. Being between 12-13 years of age was associated with a greater likelihood of reporting a 'gradual onset injury' than being younger than 12 or older than 13. Being male was associated with a higher likelihood of reporting an 'acute injury'.

These factors are likely to be confounders to the main research association analyses between specialisation and injury, and participation volume and injury. They were therefore included as covariates in the multiple logistic regression models in order to control for any confounding effects they have on the outcome variable.

Association Between Confounding Variables and Each Injury Type for Subset of Data who Answered Free-Play Question

Table F1. *Chi-square tests for independence between potential confounding variables and injury by type for subset of data reporting free-play hours per week.*

	Any injury		**Gradual onset injury**		**Acute injury**	
Variable	χ^2	***p* value**	χ^2	***p* value**	χ^2	***p* value**
School size	19.68	0.00	5.59	0.06	11.60	0.00
Decile	12.67	0.00	4.28	0.12	6.74	0.03
Specialisation	2.88	0.24	7.66	0.02	1.11	0.57
Gender[ǂ]	0.91	0.34	0.09	0.76	1.42	0.21
Age	3.32	0.19	3.06	0.22	3.55	0.17

[ǂ]Yates correction for continuity applied

Table F1 reports the results of the chi-square tests for independence for each of the three injury types. Using an alpha level of 0.1, significant relationships were found between school size and all three injury categories, between decile and 'any injury' or 'acute injury', and between specialisation category and 'gradual onset injury'.

Appendix G: Multiple Logistic Regression Tables

The following tables display the predictive strength (β coefficient (β), standard error (SE) and Wald χ^2) and the effect size (pseudo R^2 statistics) of the multiple logistic regression models built to assess the associations between specialisation and volume measures with each injury type. The β coefficient is the mathematical weighting of each variable, and measures how each independent variables contributes to the variation in the outcome (e.g. injury) (Lang & Secic, 2006). However in logistic regression this is actually displayed as the rate of change in the 'log odds' of injury occurring as the independent variable changes, and is not clinically meaningful (Field, 2005). Despite this, it is used to calculate the Wald statistic. The Wald statistic tells us if the predictor variable makes a significant contribution to the model. The higher the Wald statistic, the greater the significance of that variables contribution, and this is assessed with the *p* value (Field, 2005). The pseudo R^2 statistics in logistic regression indicate how well the model actually fits the data it was built on. In logistic regression these numbers are much lower than in linear regression R^2 statistics, and some authors question their value in logistic regression (Lang & Secic, 2006).

Table G1. *Summary of multiple logistic regression models analysing the association between specialisation and each injury type*

Injury type	**Variable**	**Coefficient β**	**Standard error**	**Wald χ^2**	***p* value**
Any injury[a]					
	Specialisation[*]				
	Moderate	0.14	0.18	0.57	0.45
	High	-0.13	0.20	0.39	0.53
	Average weekly hours	0.06	0.02	6.97	0.01
	School size[**]				
	Medium	0.46	0.19	6.04	0.01
	Large	0.77	0.25	8.49	0.00
	Decile[***]				
	Medium	0.33	0.24	1.88	0.17
	High	0.23	0.24	0.90	0.34

Gradual Onset[b]				
Specialisation[****]				
Low	0.29	0.22	1.74	0.19
Moderate	0.54	0.20	7.07	0.01
Average weekly hours	0.09	0.02	20.19	0.00
School size[**]				
Medium	0.10	0.20	0.24	0.62
Large	0.46	0.24	3.81	0.05
Age group[*****]				
12-13yrs	0.56	0.22	6.38	0.01
>13years	0.28	0.24	1.39	0.24
Decile[***]				
Medium	0.21	0.28	0.57	0.45
High	0.13	0.28	0.22	0.64
Acute[c]				
Specialisation[*]				
Moderate	-0.13	0.17	0.57	0.45
High	-0.17	0.19	0.83	0.36
Average weekly hours	0.01	0.02	0.15	0.70
School size[**]				
Medium	0.37	0.17	4.54	0.03
Large	0.45	0.22	4.30	0.04
Decile[***]				
Medium	0.24	0.24	1.03	0.31
High	0.22	0.23	0.89	0.35
Gender[******]	0.08	0.21	0.14	0.71

[a] Cox and Snell R^2 (0.04); Nagelkerke R^2 (0.05). [b] Cox and Snell R^2 (0.05) ; Nagelkerke R^2 (0.07). [c] Cox and Snell R^2 (0.02); Nagelkerke R^2 (0.02)

[*] Reference group LOW; [**] Reference group SMALL; [***] Reference group LOW; [****]Reference group HIGH; [*****]Reference group <12 years; [******]Reference group FEMALE

Table G2. *Summary of multiple logistic regression models for analysing the association between weekly participation volume and each injury type*

Injury type	Variable	Coefficient β	Standard error	Wald χ^2	*p* value
Any[a]	Average weekly hours	0.06	0.24	6.97	0.00
	School size*				
	Medium	0.46	0.19	6.04	0.01
	Large	0.72	0.25	8.49	0.00
	Decile**				
	Medium	0.33	0.24	1.88	0.17
	High	0.23	0.24	0.90	0.34
	Specialisation***				
	Moderate	0.139	0.18	0.57	0.45
	High	0.126	0.20	0.38	0.53
Gradual Onset[b]	Average weekly hours	0.89	0.02	20.30	0.00
	School size*				
	Medium	0.148	0.18	0.65	0.42
	Large	0.515	0.22	5.56	0.02
	Age group****				
	12-13yrs	0.550	0.22	6.21	0.01
	>13years	0.274	0.24	1.31	0.25
	Specialisation*****				
	Low	0.283	0.22	1.66	0.20
	Moderate	0.542	0.20	7.18	0.00
Acute[c]	Average weekly hours	0.007	0.19	0.15	0.70
	School size*				
	Medium	0.367	0.17	4.54	0.03
	Large	0.447	0.22	4.30	0.04
	Decile**				
	Medium	0.238	0.24	1.03	0.31
	High	0.216	0.23	0.89	0.35
	Specialisation***				
	Moderate	-0.125	0.17	0.57	0.45
	High	-0.171	0.19	0.83	0.36
	Gender******	0.194	0.15	1.72	0.19

[a] Cox and Snell R^2 (0.12); Nagelkerke R^2 (0.18). [b] Cox and Snell R^2 (0.02) ; Nagelkerke R^2 (0.04). [c] Cox and Snell R^2 (0.001); Nagelkerke R^2 (0.002)

* Reference group SMALL; ** Reference group LOW; *** Reference group LOW; ****Reference group <12 years; *****Reference group HIGH; ******Reference group FEMALE.

Table G3. *Summary of multiple logistic regression models for analysing the association between participating > 8 months of the year in one sport and each injury type.*

Injury type	**Variable**	**Coefficient β**	**Standard error**	**Wald χ^2**	***p* value**
Any[a]	Participate >8 months	0.44	0.18	6.33	0.01
	Decile[*]				
	Medium (4-7)	0.38	0.24	2.42	0.12
	High (8-10)	0.33	0.24	1.89	0.17
	School size[**]				
	Medium (500-999)	0.47	0.19	6.39	0.01
	Large (>1000)	0.65	0.25	6.99	0.01
Gradual Onset[b]	Participate >8 months				
		0.89	0.02	20.30	0.00
	Age group[***]				
	12-13yrs				
	>13years	0.148	0.18	0.65	0.42
		0.515	0.22	5.56	0.02
	School size[**]				
	Medium				
	Large	0.550	0.22	6.21	0.01
		0.274	0.24	1.31	0.25
Acute[c]	Participate >8 months	0.28	0.17	2.95	0.09
	Gender[****]	0.17	0.15	1.41	0.24
	School size[**]				
	Medium	0.35	0.17	4.05	0.04
	Large	0.38	0.22	3.12	0.08
	Decile[*]				
	Medium	0.25	0.23	1.09	0.30
	High	0.21	0.23	0.88	0.35

[a] Cox and Snell R^2 (0.03); Nagelkerke R^2 (0.05). [b] Cox and Snell R^2 (0.02) ; Nagelkerke R^2 (0.03). [c] Cox and Snell R^2 (0.02); Nagelkerke R^2 (0.03)

[*] Reference group LOW (1-3); [**] Reference group SMALL (<500); [***]Reference group <12 years; [****] Reference group FEMALE.

Table G4. *Summary of multiple logistic regression models for analysing the association between participating more hours/week than age in years and each injury type.*

Injury type	**Variable**	**Coefficient β**	**Standard error**	**Wald χ^2**	***p* value**
Any[a]	Exceed hrs/week based on age	0.91	0.49	3.46	0.06
	School size*				
	Medium (500-999)	0.51	0.19	7.56	0.01
	Large (>1000)	0.74	0.25	8.89	0.00
	Specialisation**				
	Moderate	0.14	0.18	0.55	0.46
	High	-0.15	0.20	0.52	0.47
	Decile***				
	Medium (4-7)	0.33	0.24	1.80	0.18
	High (8-10)	0.28	0.24	1.33	0.25
Gradual Onset[b]	Exceed hrs/week based on age	0.89	0.33	7.23	0.01
	School size*				
	Medium	0.24	0.18	1.75	0.19
	Large	0.55	0.22	6.49	0.01
	Specialisation****				
	Low	0.30	0.22	1.92	0.17
	Moderate	0.56	0.20	7.80	0.01
	Age group*****				
	12-13yrs	0.57	0.22	6.80	0.01
	>13years	0.32	0.24	1.84	0.18
Acute[c]	Exceed hrs/week based on age	0.42	0.36	1.32	0.25
	School size*				
	Medium	0.37	0.17	4.65	0.03
	Large	0.44	0.22	4.25	0.04
	Specialisation**				
	Moderate	-0.12	0.17	0.50	0.48
	High	-0.17	0.19	0.83	0.36
	Gender******	0.19	0.15	1.69	0.19
	Decile***				
	Medium	0.23	0.24	1.00	0.32
	High	0.21	0.23	0.88	0.35

[a] Cox and Snell R^2 (0.03); Nagelkerke R^2 (0.05). [b] Cox and Snell R^2 (0.03) ; Nagelkerke R^2 (0.04). [c] Cox and Snell R^2 (0.02); Nagelkerke R^2 (0.03)

* Reference group SMALL (<500); **Reference group LOW; *** Reference group LOW (1-3); ****Reference group HIGH; *****Reference group <12 years; ****** Reference group FEMALE.

Table G5. *Summary of multiple logistic regression models for analysing the association between playing > 2:1 ratio organised sport: free-play and each injury type.*

Injury type	**Variable**		**Coefficient β**	**Standard error**	**Wald χ^2**	***p* value**
Any[a]	Exceed 2:1 Organised : free-play		0.11	0.19	0.35	0.55
	School size*					
		Medium (500-999)	0.57	0.20	8.45	0.00
		Large (>1000)	0.63	0.25	6.19	0.01
	Decile**					
		Medium (4-7)	0.36	0.26	1.94	0.16
		High (8-10)	0.44	0.25	3.07	0.08
Gradual Onset[b]	Exceed 2:1 Organised : free-play		0.42	0.18	5.82	0.02
	Specialisation category***					
		Moderate	0.24	0.19	1.59	0.21
		High	-0.35	0.23	2.34	0.13
	School size*					
		Medium	0.27	0.19	2.03	0.15
		Large	0.52	0.23	5.13	0.02
Acute[c]	Exceed 2:1 Organised : free-play		-0.08	0.16	0.25	0.52
	School size**					
		Medium	0.42	0.18	5.45	0.02
		Large	0.49	0.23	4.71	0.03
	Decile*					
		Medium	0.29	0.24	1.46	0.23
		High	0.03	0.20	0.02	0.39

[a] Cox and Snell R^2 (0.03); Nagelkerke R^2 (0.04). [b] Cox and Snell R^2 (0.02) ; Nagelkerke R^2 (0.04). [c] Cox and Snell R^2 (0.02); Nagelkerke R^2 (0.02)

* Reference group SMALL (<500); ** Reference group LOW (1-3); ***Reference group LOW