Maturation Status in Premier Secondary School Sports Teams

Tom Cooper

A Dissertation submitted to

Auckland University of Technology

in partial fulfilment of the requirements for the degree of

Master of Sport, Exercise and Health (MSEH)

2022

School of Sport and Recreation

Abstract

Youth have high levels of participation in sport around the world, in particular, New Zealand. In the everchanging world of sport, many sports clubs and academies around the world are placing an emphasis on selecting athletes with expected long-term high potential at ages as young as nine. With the significant variation in growth amongst youth it is thought that this may influence team selection based upon temporary maturity-related advantages in physical capabilities. Additionally, the peak adolescent growth period has been linked to an increase in injury risk. For both reasons maturity timing and status needs to be considered in the selection process for youth sport teams.

A cross-sectional study was conducted, examining biological maturity and injury history of youth boys in a secondary school academy sports programme. Anthropometric measurements (standing height, seated height, and weight) were evaluated across 98 male students. The estimated percent of predicted adult height (%PAH) was obtained from these measurements using the Khamis-Roche method and this was used to estimate maturity status (pre, circa or post-peak height velocity [PHV]). The %PAH was also expressed as a z-score relative to published reference data to determine if participants were early, on-time or late maturing. Participants also took part in a face-to-face paper-based questionnaire that recorded injury history over the prior 3 months. Over 90% of participants were either circa- or post-PHV. Early maturers accounted for 65.3% (n = 64) of participants across all sports while late maturers only represented 1% indicating a clear bias (observed frequency significantly different to expected frequency; chi-square = 15.6; $p<0.001$). The injury history questionnaire identified that 60% (n = 52) of participants had experienced an injury but there was no clear association with maturity status (OR = 0.84 to 1.56; $p>0.05$). Improved understanding and awareness of the potential for maturity to influence selection in secondary school academy sport is needed.

Recommendations based on these findings include educating coaches, parents, and players about biological maturity and how this can impact the selection, performance, and training of youth athletes. This will raise awareness of potential selection biases and awareness as to why youth athletes may go through stages of increases or decreases in ability and competency as they mature. The implementation of maturity estimation methods and monitoring where possible should be considered. Using the maturity estimations to enhance the structure and load of training programmes and to allow bio-banded training and playing opportunities may be beneficial.

Table of Contents

List of Tables

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 accepted for the award of any other degree or diploma of a university or other institution of higher learning, except where due acknowledgement is made.

Chapter 3 of this dissertation represents a separate paper that is in preparation for submission to peer-reviewed journals. The contribution by the various co-authors and myself to this paper is outlined at the beginning of the dissertation. All co-authors have approved the inclusion of the joint work in this Masters dissertation.

Tom Cooper

September 2022

Candidate Contributions to Co-Authored Papers

Chapter 3 Cooper, T., & Whatman, C., (2022). Maturation Selection Bias and Injury in a Secondary School Sports Academy: A Cross-Sectional Study. To be submitted to *New Zealand Journal of Sports Medicine.*	Cooper 80% Whatman 20%

We, the undersigned, hereby agree to the percentages of participation to the chapter identified above:

	
Tom Cooper	Chris Whatman

Acknowledgements

Research is something that I have always been interested in. After a long time coming with many highs and lows it is finally been achieved. I have been able to work in and around some amazing people, enabling me to learn more and more every day. These people have been able to help me develop as an individual and create a piece of work I will be forever proud of.

Firstly, I would like to thank my supervisor, Chris Whatman. Thank you for agreeing to assist me and provide guidance through the duration of the MSEH dissertation. I am very appreciative for all your help and knowledge in the youth sport and academic research areas. I am glad to have had a supervisor that is so passionate about the topic that I was wanting to study. I have learnt a lot along the way and hope to share it with others in the future. Throughout all the meetings and reviews during the past 18 months and especially during our Covid-19 lockdowns I have been so lucky to have been inspired about the research time after time.

Thank you to the staff within the school where the study took place for allowing me to conduct my research with ease and for any assistance from teachers where required.

To all the postgraduate staff, thank you for creating such a memorable MSEH experience. Further, to the lecturers of my undergraduate papers, forming the base to be able to continue my studies further. Then to the postgraduate lecturers, I have learnt more than I could have imagined in all the papers I took. Using the knowledge, I have gained to aid my studies and coach those around me in the youth athlete development and strength and conditioning space.

Lastly, I want to thank all my family and friends who have supported me from the very beginning. The postgraduate academic journey is an achievement I can now share and reflect on with those others who have also fulfilled this milestone. Thank you, everyone, for everything.

Ethical Approval

Ethical approval for this research was granted by the Auckland University of Technology Ethics Committee (AUTEC) on 12th April 2022 for a period of three years:

- AUTEC: 22/47 – Links between the adolescent growth spurt, team selection and injury history in secondary school sports teams.

Chapter 1: Introduction

1.1 Background

Youth sport participation is extensive in many countries worldwide. New Zealand has an extremely high rate of active sport and recreation participation with 94% of young people (5-17 years of age) taking part (Sport New Zealand - Active NZ 2018 Participation Report, 2019). Similarly, overseas countries such as Canada, have high participation rates (76% of youth aged 11–15-year) (ParticipACTION Canada 2018). Other large countries, for instance, America and England, also have a large volume of youth playing sports however the portion of the population is far fewer, 58% and 63% for America and England respectively (National Youth Sports Strategy, 2019; Sport England Active Lives Children and Young People Survey, 2019)

Younger children tend to have high participation rates in sport due to the enjoyment factor. However, as youth get older their sporting goals become more closely linked with team selection and less focused on recreational participation and learning new skills (Ingrell et al., 2019, 2020). Sports team ability-based trials can begin as young as nine years of age in sports such as football (Read et al., 2016; Sweeney et al., 2021). Team selection during adolescence tends to lean towards the selection of players that possess greater physical capability and subsequent athletic performance. These characteristics are advantageous in a sport like football as it requires high levels of physical performance, technical and tactical knowledge and rapid decision making (Sheppard et al., 2006; Ward & Williams, 2003; Williams & Reilly, 2000).

In football and many other sports, increased physical capability is linked to biological maturation and the adolescent growth spurt. For example, more mature players of the same chronological age have been observed to have increased muscle mass, resulting in greater strength, sprint, change of direction and jump ability as well as better static and dynamic balance performance (Hammami et al., 2016; John et al., 2019 & Philippaerts et al., 2006). These physical advantages have been identified as a primary reason for a bias in selection toward players who mature early (Patel et al., 2019). As a result, several authors have highlighted that biological maturation needs to be considered when selecting youth for sports teams (Figueiredo et al., 2009; Hill et al., 2020; Johnson et al., 2017; Philippaerts et al., 2006). In youth football specifically, concerns have been raised that maturity timing plays a considerable role in the selection of players for premier teams and/or academies (Johnson et al., 2017). Early maturing players are seen to physically dominate their less mature counterparts, providing them with a significant advantage (Hammami et al., 2016; Lesinksi et al., 2020; Papadopoulou et al., 2019 & Philippaerts et al., 2006). The non-selection of late maturing players at the youth level is cause for concern as the maturity-related enhancements are only prevalent through adolescence and in some cases early adulthood but cease to exist in elite adult sport (Helsen et al., 2005; Vaeyens et al., 2005; Hirose, 2009).

Given its impact on physical capability, variation in biological maturation is an issue that needs to be considered when making decisions regarding future potential. Talent identification (ID) and development academies aim to identify and support athletes with expected long-term potential in sport. There are several components that form the base of talent identification, physical (height, weight), physiological (speed, power, strength) technical (dribbling, shooting) and cognitive (decision making, game understanding). Academy selectors and team coaches involved in the selection process are required to identify the players with the greatest-long term potential. These select few players are subsequently invested in, in terms of time, resources and funding (Vaeyens et al., 2008).

Knowledge of biological maturity status in youth sport is also important as it has been linked to injury risk. Injuries play a considerable role in long-term athlete development (LTAD). Periods of rapid growth, which are highly variable in youth athletes can lead to an increase in injury risk and severity. During maturation, youth undergo significant anthropometrical, neuromuscular, and structural changes that likely alter injury risk. The period of most concern is often around the time of PHV (Bult et al., 2018; Johnson et al., 2019; van der Sluis et al., 2014) and there is evidence injury risk varies with the stage of maturation. Players at or near (circa) their PHV are reportedly more likely to experience growth related injuries than their pre-PHV and post-PHV counterparts. This is likely associated with the rapid increases in leg length and stature circa-PHV resulting from the intense activity in growth, particularly of long bones..

Due to different mechanisms of injury being more prevalent at different stages of maturation injury types, rates and severity vary between pre, circa and post-PHV (Bahr & Krosshaug, 2005; Johnson et al., 2019). Sports injuries can be categorised as either acute or overuse. An acute injury is commonly an injury that occurs with a sudden onset, is often quite severe (sprained ankle, strained hamstring, bone fracture) and is primarily caused by a traumatic event such as rapid acceleration or deceleration, falling, and/or colliding with an opponent (Bahr & Krosshaug, 2005). Overuse injuries are commonly the result of prolonged exercise with the overuse of a particular body segment or a high frequency of training without adequate rest between sessions (Wilder & Sethi, 2004). Common growth-related injuries in youth athletes are Osgood-Schlatter (knee) and Severs disease (heel) and these are often associated with overuse during a rapid period of growth.

Injury rate is commonly measured as injuries per 1000 player hours. Pre-PHV athletes have been reported to experience the lowest injury rate (10.7-11.5/1000h) during a season compared to athletes circa PHV (24.5/1000h) and post-PHV (16.4/1000h) (Johnson et al., 2019). It has been observed that during pre-PHV overuse injuries become more prominent the closer the player is to circa-PHV, this is a critical reason as to why the criteria for different stages of maturation need to be identified (Bult et al., 2018; Johnson et al., 2019; Monasterio et al., 2021; van der Sluis et al., 2014). The two most common growth-related (circa PHV) injuries are Sever's disease and Osgood-Schlatter disease and this is likely attributed to growth from distal to proximal. These two growth related injuries have been reported to account for 46% of all injuries circa-PHV. The location of growth-related injuries changes during maturation with increasing rates of pelvic injuries later in maturation and less Severs and Osgood-Schlatters. This injury pattern is likely because growth progresses from distal to proximal. Among post-PHV players the most common types of injury are muscular (39%), ankle joint/ligament (13%) and knee joint/ligament (11%). Growth-related injuries post-PHV reduce and only account for 9% of injuries. Muscular injuries post-PHV most commonly occur in the quadriceps, hamstring and adductors (Monasterio et al., 2021). This is associated with the increase in muscle mass, subsequently greater moments of inertia on the players joints may exceed the current muscle capacity (Dupré et al., 2020.)

Injury severity can be measured as the duration of time (days) a player is unable to participate fully in training or a game due to injury (Bult et al., 2018, Johnson et al., 2019). Findings suggest that circa-PHV youth experience the greatest number of days lost, followed by post-PHV youth (Johnson et al., 2019). This is linked to the type of injuries commonly experienced at each stage of maturation and the recovery times. Circa and post-PHV players generally experience more traumatic injuries that take longer to recover from than pre-PHV players, assuming injuries are managed appropriately (Bult et al., 2018; Monasterio et al., 2021; van der Sluis et al., 2014). Injury burden is calculated by multiplying the incidence rate and mean days missed per injury (severity). Injury burden is a useful tool for identifying the stage of maturation at which an individual is likely to experience the greatest impact from injuries. Circa-PHV players have been observed to have the greatest injury burden (560 days/1000h) as they have the greatest incidence rates and often the greatest mean number of days missed per injury. Post-PHV players have an injury burden (435 days/1000h) that is significantly higher than pre-PHV (182 days/1000h) (Johnson et al., 2019). Post-PHV players have injuries similar in severity to circa-PHV players, with a lower incidence rate. Whilst pre-PHV players have the lowest incidence rate and injury severity (Bult et al., 2018 & Johnson et al., 2019).

1.2 Biological Maturity Assessments

There are several methods used to estimate biological maturity. All the methods have their limitations, and the application of each method is dependent on the resources available and the specific environment. Maturity estimation methods can be categorised by their design and application. The most common method in clinical research is the assessment of hand-wrist radiographs. Common methods are the Greulich-Pyle (GP), and Fels, hand-wrist x-ray assessments (Cavallo et al., 2021; Coelho-e-Silva et al., 2010; Malina et al., 2015; Tribolet et al., 2018). Assessment of hand-wrist x-rays allows for an estimation of bone age/maturity and the characterisation of the shape and change in structure of the bones makes it possible to categorise individuals based upon bone maturity. A second method that is less commonly used in clinical research is assessment of secondary sexual characteristics via the Tanner assessment of secondary sexual characteristics (Dorn et al., 2006). Evaluation of secondary sexual characteristics is based on 5 stages of development of these characteristics. These stages range from observations expected at early childhood (stage 1) to mature adult (stage 5) (Marshall & Tanner, 1970). While x-ray assessment and assessment of secondary sexual characteristics are likely most accurate, these methods are invasive and require highly qualified and skilled technician/specialists and are generally no suitable for applied team sport settings.

A further category of biological maturity assessments is estimations based on anthropometric measurements. This method is the most common in a field setting as it is the easiest to perform without a high degree of specialist training or equipment, is least invasive, time efficient, cost effective and easily accessible. Additionally, estimates based on anthropometric measurements are the most commonly reported in applied team sport settings. Most estimations are based on the Khamis-Roche method (Khamis and Roche, 1994), Mirwald method (Mirwald et al., 2002) and the method reported by Fransen et al., 2018 (Towlson et al., 2021). These methods use a variety of anthropometric measurements including height, seated height, weight and parent height. Their respective maturity estimation equations can be applied to estimate maturity status, maturity offset and predicted adult stature. The Khamis-Roche method applies a specific calculation that uses date of birth, height, weight, and mid-parent height to estimate percentage of predicted adult stature (%PAH) and from this maturity status can be estimated. The %PAH method is considered a suitable method for estimating timing of peak height velocity (PHV) and has recently been preferred to the Mirwald method in the sports science literature (Towlson et al., 2021).

1.3 Structure of the Dissertation

In agreement with the Auckland University of Technology's Format Two, this dissertation contains four chapters. An introduction/rationale (Chapter 1), a literature review (Chapter 2), a formatted chapter suited for journal publication (Chapter 3), as such some repetition of information does occur between chapters. Concluding with a summary of preceding chapters and a general discussion incorporating research findings, proposed practical implications of this research, study limitations, and identified areas of future research. The referencing format has been standardised to the American Psychological Association 7th Edition, with a single reference list prepared for the dissertation.

1.4 Purpose of the Dissertation

This dissertation had two primary questions:

1. Is there a selection bias towards more mature youth in secondary school sports teams?
2. Is there an association between maturation status and recent injury in secondary schools sports team athletes?

Chapter 2 is a narrative review of the current literature discussing the evidence for a maturation selection bias in youth sport. Chapter 3 is a cross-sectional study investigating potential maturation selection bias in secondary school academy sports teams and maturation associated injuries. Finally, Chapter 4 is a discussion/conclusion on the key findings of the overall dissertation, including any limitations and practical applications/recommendations for future research.

Prelude to Chapter 2

A narrative literature review was conducted to examine the current evidence for the existence of a maturity based selection bias in youth sport. During the search for relevant literature, it became apparent studies had been conducted in three main contexts: maturity comparison between selected and non-selected youth players, maturity comparison between players at different playing levels and the maturity comparison in a youth academy system including players identified as talented.

Chapter 2: Maturation Selection Bias in Youth Sport: A Narrative Review

2.1 Introduction

The aim of this chapter is to provide a narrative review appraising the academic literature exploring (i) the evidence for a maturation selection bias in youth sport, (ii) differences that exist between sports and (iii) differences that exist between males and females. This chapter describes what maturation selection bias is, why it is important to consider maturation selection bias, how to identify bias and the strength of evidence that the bias actually exists in youth sport.

A literature search was performed in May-July 2021 using the following electronic databases, EBSCO health, SCOPUS, SPORT Discus and Web of Science. Key search terms used included matur*, youth OR young OR adolescen*, selec*, spor*, bias. The search was limited to full text English publications published between 2000-2021. To be included in the review, studies had to be original research papers in English with a primary aim of examining the maturation selection bias in youth sport. Studies were excluded if they were review or expert opinion. The search returned 13 original research studies. The total participants across all the studies was 3681 (male= 3351, female= 330). The mean sample size was 207 with a range of 55 to 868. The age range of participants was from 9-18 years. The sports investigated by the studies included football/soccer, basketball, American football, ice hockey, volleyball, baseball, tennis and Australian Football (AFL).

For the purpose of the review, it was decided that the presence of a selection bias would be defined as an overrepresentation of early maturing/post-PHV players or an underrepresentation of late maturing/pre-PHV players.

2.2 Findings

2.2.1 Methods used to estimate maturation status and timing

Across the studies reviewed five methods for estimating maturation status were used (*Khamis-Roche, Mirwald 2002, Tanner-Whitehouse, Fels and Fransen et al., 2018*). Seven of thirteen studies used invasive methods of either TW or Fels. The remaining six used Khamis-Roche, Mirwald and Fransen, twice respectively. The method of assessment varies between studies due to a multitude of factors such as sample size, funding, accessibility, context and time taken for assessment. Authors regularly noted the benefits of using non-invasive measures including the ability to gather a greater sample size in a shorter space of time, using less resources that are more accessible and that testing could be performed without radiograph expertise.

The two most common field-based methods reported in the reviewed studies to estimate maturation status and maturity timing, were the Khamis-Roche method and the Mirwald method. Maturation status identifies what stage of maturation a player is in at the time of data collection relative to their Peak Height Velocity (PHV). PHV is a specific moment in time where an adolescent experiences their fastest growth in height/stature. The stages of maturation are categorised as pre, circa and post-PHV. The most commonly reported estimation method in the sports science literature recently is the Khamis-Roche method which estimates predicted adult height (PAH) and then calculates the current percentage of PAH (%PAH). Percentage of PAH thresholds have been reported to determine maturity status and the most commonly used thresholds appear to be pre-PHV (<85% PAH), circa-PHV (85-96% PAH) and post-PHV (>96% PAH) (Cumming et al., 2017; Johnson et al., 2019; Salter et al., 2022). These %PAH thresholds are reflective of a circa-PHV threshold of ± 1.0 year. A less conservative criterion for %PAH maturity status classification is pre-PHV (<88% PAH), circa-PHV (88-93 PAH) and post-PHV (>93% PAH). These %PAH thresholds are reflective of a circa-PHV threshold of ± 0.5 year (Salter et al., 2022). The Khamis-Roche method estimates %PAH using decimal age, standing stature/height (cm) and body mass (kg) and also requires measurement (or estimation) of biological parent standing stature. The likely reason for this method being widely used is that it is time friendly, non-invasive and an expert physician is not required to conduct the measurement. Further this method has recently been recommended by Towlson et al. (2021) who reported that the method produced more accurate predictions than the other commonly reported method, the Mirwald method (Parr et al., 2020). Their 5-year longitudinal study observed that 96% of the sample population had their PHV between 85-95% PAH. This was in comparison to only 61% using maturity offset (age ±1-year) calculated using the Mirwald method. The Mirwald method estimates maturity status using a maturity offset which is calculated as the difference between chronological age (CA) and predicted age of peak height velocity (APHV). APHV is calculated based on measurements of height, seated height and weight. A maturity offset ≥1 indicates that an individual is in their post-PHV stage. A maturity offset from -0.99 to 0.99 indicates an individual is circa-PHV (the window where PHV is expected to occur). A maturity offset of ≤-1 indicates the individual is in their pre-PHV stage.

Maturity timing identifies whether the participant is “early, on-time, or late” in terms of their biological maturation relative to players of the same chronological age. Using the Khamis-Roche method percent of PAH is compared to age and sex specific standards to determine the degree to which a player is advanced or delayed in maturation, often reported as a z-score. Several previous studies have used a z-score criteria of -1.0 to 1.0 to identify ‘on-time’, z-score below −1.0 as ‘late’ and z-score above 1.0 as ‘early’ (Hill et al., 2020; Hirose & Hirano, 2012; Johnson et al., 2017; Myburgh et al., 2016). This criterion has been criticized as too conservative as it would categorise both an individual with a z-score of 0.99 and -0.99 as ‘on-time.’ A less conservative criteria has also been proposed where a z-score of -0.5 to 0.5 is ‘on-time’, below −0.5 is ‘late’ and a z score above 0.5 is ‘early’. This reduces the window of individuals categorised as ‘on-time’ and produces estimates that may more accurately reflect players maturing ‘on-time’ (Hill et al., 2020; Johnson et al., 2019; Ostojic et al., 2014). Football academy players of the same CA may vary by up to 6 years in biological age (Johnson et al., 2009). To examine for a maturation selection bias using the Khamis-Roche method, the percentage of players at each maturation status and timing classification is calculated. A bias toward more mature players is indicated by an overrepresentation of players who are classified as ‘early’ maturers (z-score >0.5) or at post-PHV (stature>93%PAH).

Table 1

Overview of studies reporting on potential maturation selection bias

Study	**Study Design**	**Sport**	**Participants**	**Outcomes**	**Selection Bias (Yes/No)**
Baxter-Jones, Barbour-Tuck, Dale, Sherar, Knight, Cumming, Ferguson, Kowalski & Humbert, 2020	Cross-sectional Cohort Study	Multiple	N =868 (67% Male) Youth Saskatchewan Sports Athletes Age Range 11-17	*Gender APHV:* Selected males had a significantly younger APHV, selected females displayed no significant difference *Sport APHV:* All sports selected players with a younger APHV *Age Group APHV:* All age groups across the sports selected players with a younger APHV except for U13-14 male football.	Yes Selection bias in male but not females across all sports Exception for U13-14 males, no bias observed.
Chibane, Hautier, Gaudino, Massarelli & Mimouni, 2007	Cross-sectional Cohort Study	Football	N =91 Male Algerian soccer players Mean age 16.6 years	*Age to PHV* *Elite:* Mean age to PHV = 1.11 years *Sub-elite:* Mean age to PHV = 0.46 years	Yes Significant bias towards more mature players in the elite and less mature players at sub-elite level.
Figueiredo, Gonçalves, Coelho E Silva & Malina, 2009	Longitudinal Cross-sectional study	Football	N = 159 Males Portuguese youth soccer players Age Range 11-15	*Age Group 11-12:* No significant difference at baseline for skeletal age across any ability *Age Group 13-14:* (SA-CA) Elite = 0.8 years Club = 0.4 years Drop-out = 0.2 years	Yes At older ages (13-14) elite level players were more skeletally mature than sub-elite players. No bias observed at younger ages (11-12)

Study	Study Design	Sport	Participants	Outcomes	Selection Bias
Hill, Scott, Malina, McGee & Cumming, 2020	Longitudinal Cross-sectional study	Football	N =202 Males Southampton football club academy Age Range 8-17	*Percentage of players classified as early, average and late:* U10: 9% early, 59% average and 32% late U11: 12% early, 55% average and 33% late U12: 25% early, 57% average and 18% late U13: 38% early, 49% average and 13% late U14: 45% early, 48% average and 7% late U15: 52% early, 47% average and 1% late U16: 54% early, 45% average and 1% late	Yes Bias towards more mature players from U13 onwards. Increasing as chronological age increased.
Hirose, N. 2009	Cross-sectional Cohort Study	Football	N =332 Males Japanese Youth Age Range 9-16	*Maturity offset of selected and non-selected players:* U11-Selected: 0.2 ±1.0 U11-Non-selected: -0.6 ±1.0 U13-Selected: 0.8 ±0.8 U13-Non-selected: -0.2 ±1.1 No significant difference in maturity offset between selected and non-selected players in any other age groups	Yes A selection bias towards more mature players was observed in the U11 and U13 age groups only.
Hirose & Hirano, 2012	Cross-sectional Cohort Study	Football	N =181 Males Japanese Youth Age Range 9-16	*Percentage of players classified as early, average and late:* U13: 58% early, 35.5% average and 6.5% late	Yes Only observed in U13 age group

Study	Study Design	Sport	Participants	Outcomes	Selection Bias
Johnson, Farooq & Whiteley, 2017	Longitudinal Cross-sectional study	Football	N =472 Males Manchester United Football academy, England (n=293) Middle Eastern Sports Academy, (n=179). Age Range 9-17	*Percentage of players classified as early, average and late:* U10: 12% early, 68% average and 20% late U11: 24% early, 58% average and 18% late U12: 28% early, 61% average and 11% late U13: 30% early, 59% average and 11% late U14: 39% early, 52% average and 9% late U15: 45% early, 52% average and 3% late U16: 65% early, 33% average and 2% late U17: 78% early, 20% average and 2% late	Yes Bias towards more mature players from U12 onwards. Increasing as chronological age increased.
Malina, Peña Reyes, Eisenmann, Horta, Rodrigues & Miller, 2000	Cross-sectional Cohort Study	Football	N =135 Male Portuguese elite youth soccer players Age Range 10.7-16.5	*Percentage of players classified as early, average and late:* U11-12: 21% early, 58% average and 21% late U13-14: 38% early, 55% average and 7% late U15-16: 58% early, 39% average and 3% late	Yes Bias towards early maturing players in the U13-14 and U15-16 age groups
Myburgh, Cumming, Coelho E Silva, Cooke & Malina, 2016	Cross-sectional Cohort Study	Tennis	N =91 (52% Male) Great Britain elite youth tennis players Age Range 8-17	*Comparison of SA and CA in males and females* *Males:* In the U14 and U-16 age groups the players had a SA far greater than CA, +1.23 and + 0.75 respectively. At the younger age groups the SA and CA were not significantly different *Females:* Throughout each age group U10-U16 SA was greater than CA (0.30-0.89).	Yes Selection bias towards more mature players was evident in both males and females. Except in males younger than U13.

Study	Study Design	Sport	Participants	Outcomes	Selection Bias
Ostojic, Castanga, Calleja Gonzales & Jukic, 2014	Longitudinal cohort study	Football	N =55 Serbian youth footballers Age Range 14-15	*Maturation timing status:* Early = 44% Average = 35% Late = 21%	Yes Selection bias towards more mature players. An overrepresentation of early matures and underrepresentation of late maturers.
Sherar, Baxter-Jones, Faulkner & Ruseel, 2007	Cross-sectional Cohort Study	Ice Hockey	N= 619 Male Saskatchewan Youth hockey players Age Range 14-15	*APHV:* Not selected at first trial: 13.48 Selected at first and not second: 13.31 Selected for the team: 12.81	Yes Selected players had a younger APHV than non-selected players
Toum, Tribolet, Watsford & Fransen, 2020	Cross-sectional Cohort Study	AFL	N= 227 Male Australian Youth AFL players Age Range 12-15	*APHV:* Not selected: 14.1 Selected for the team: 13.8	Yes Selected players had a younger APHV than non-selected players
Tribolet, Bennett, Watsford & Fransen, 2018	Cross-sectional Cohort Study	AFL	N= 277 Australian Youth AFL players Age Range 12-15	*APHV:* Not selected: 14.3 Selected for the team: 13.8	Yes Selected players had a younger APHV than non-selected players

2.2.2 The evidence for a selection bias

The findings from all 13 studies reviewed reported a significant selection bias towards players who were biologically more mature. Males and Females of different ages and sports have been found to be affected by a maturation selection bias to varying degrees. The maturation selection bias was measured and reported differently across all studies, and this makes it difficult to compare findings directly. There is a clear gap in the literature surrounding selection bias in youth females. This has clearly not been investigated as widely as in youth males. Five of the studies reported the relationship between maturity and selection and non-selection of players (Baxter-Jones et al., 2020; Chibane et al., 2007; Sherar et al., 2007; Toum et al., 2020; Tribolet et al., 2018). Identification of a selection bias towards more mature players was observed by a comparison of the age of peak height velocity (APHV) between selected and non-selected players. APHV was examined in selected and non-selected players from a diverse range of sports including hockey, basketball, baseball, volleyball, American football and soccer among males and females from 11-17 years of age. A significant selection bias towards more mature players was observed in each sport across the age groups in males only with no significant bias in the female teams (Baxter-Jones et al., 2020). In Australia the APHV of selected and non-selected male U-16 high level AFL players was reported. A small yet significant difference of 0.27 years ($p = 0.047$, ES= 0.06) was observed between the APHV of selected (13.8 yrs ± 0.4) and non-selected (14.1 yrs ± 0.7) players (Toum et al., 2020). Similar findings have been reported in a similar population consisting of 12–15 year-old AFL players, where selected players had a younger APHV of 0.5 years (13.8 yrs ± 0.6), compared to non-selected players (14.3 yrs ± 0.6) (Tribolet et al., 2018).

A further three studies in football reported bias based on the skeletal age (SA) of players classified by playing level (Figueiredo et al., 2009; Hirose, 2009; Ostojic et al., 2014). Portuguese elite male youth players were identified as players selected for regional teams or elite clubs. Club players were identified as players who remained at the same provincial club. Finally, players classified as drop-out discontinued playing football. Elite/selected players had a maturity offset of 0.8 ±1.1, club/non-selected (0.4 ±1.1) and drop-out/non-selected (0.2 ±0.9) (Figueiredo et al., 2009). A bias toward more mature players was the most significant at elite/selected level. By comparison the non-selected players had a lower maturity offset. These findings concur with the previously mentioned studies where selected players (elite) were advanced in maturation compared to their non-selected counterparts. In a Japanese male youth population, a selection bias towards more mature players was observed in U-11 and U-13 age groups only. Selected players had a maturity offset of (U-11=0.2 ±1.0 and U-13=0.8 ±0.8) respectively. Non-selected players had a maturity offset of (U-11=-0.6 ±1.0 and U-13 -0.2 ±1.1) respectively (Hirose, 2009).

Finally, three studies examined athletes selected for elite level football and tennis training groups/academies. Observations across all these studies identified a selection and retention bias favouring more mature players. A trend was identified that saw an increase in bias towards more mature players footballers as chronological age increased from 8 to 17 years (Hill et al., 2020 & Johnson et al., 2017). In younger age groups (U-8-U12 years) no significant bias is apparent (proportion early=22%, on-time=48% and late=30%) (Hill et al., 2020). A change in the distribution of player maturity status begins to emerge in the U-14 ages groups (Hill et al., 2020: Johnson et al., 2017; Myburgh et al., 2016). As chronological age increases, the underrepresentation of late maturing players is evident across all of the studies, resulting in the overrepresentation (53%-78%) of early maturing players in the U-15 age groups and above (Hill et al., 2020; Johnson et al., 2017). Comparably, there was an underrepresentation of late maturing players in elite youth tennis. However, the incremental overrepresentation of early maturing players was not evident, rather the underrepresentation of late maturers (Myburgh et al., 2016).

The bias reported in the studies reviewed was observed across a wide range or sports including football/soccer, basketball, American football, ice hockey, volleyball, baseball, tennis and Australian Football (AFL) across varying age groups (8-17 years). Two studies reported a small bias towards more mature players (Hirose & Hirano, 2012; Malina et al., 2000). In Japanese youth footballers only one small age range (U12 to U13) displayed a significant difference in maturity timing across age groups ranging from U10 to U16. In the U-13 group most of the players (58%) were categorised as maturing early and only 6.5% late, indicating a selection bias towards more mature players (Hirose & Hirano, 2012). Similarly in elite level Portuguese youth footballers it was observed that there was only a bias towards selecting more mature players in the 15-16 years age group in comparison to the 11-12 and 13-14 year age groups. When adjusted for players selected for the youth national team from these elite club level teams there was a bias towards the selection of more mature players (67.9%). However, the bias was similar in non-selected players with 70.8% of non-selected players classified as early maturers or skeletally mature (Malina et al., 2000). These findings indicate that the apparent bias in this study is not representative of a selection bias towards more mature players rather that there was simply a greater proportion of players who were early or mature that were available for selection. A possible reasoning for this is that late maturing players may have already been deselected from the system at an earlier point (Figueiredo et al., 2009; Johnson et al., 2017).

2.2.3 Selection Bias Across Different Sports

Eight studies (61%) examined football/soccer only, two examined Australian Football (AFL), one examined ice hockey, one examined tennis and the final study examined a vast array of popular

American sports (soccer, basketball, hockey, baseball, volleyball and American football). The likely reason for football being the most widely studied sport is that it is the most popular sport to play worldwide, particularly in the United Kingdom and Europe, where most of the research has been conducted. Football team selection occurs at a relatively young age and many elite clubs have well equipped academies with the resources to monitor maturation and have research based LTAD models to facilitate youth development into senior level (Lloyd & Oliver, 2012; Van Hooren & De Ste Croix, 2020).

In all the studies that involved football, excluding (Hirose & Hirano, 2012) a significant maturation selection bias was observed in selected, retained, and elite players (Baxter-Jones et al., 2020; Chibane et al., 2007; Figueiredo et al., 2009; Hill et al., 2020; Hirose, 2009; Johnson et al., 2017; Ostojic et al., 2014). All the studies vary in terms of study population regarding ability level, age range and population ethnicity. English elite youth football academies had players as young as 8, and as old as 16 years of age. In the U-12 grade and below there was no significant selection bias towards more mature players (early=24%, on-time=57% and late=19%) (Hill et al., 2020). However, from the U-14 age group and above there was a significant bias towards the selection of more mature players, the bias increasing as chronological age increased (Hill et al., 2020; Johnson et al., 2017). Within Portuguese players of varying abilities there was again no significant selection bias at the U-12 grade. However again, from the age group, U-14 and above a bias towards the selection of more mature players was observed (Figueiredo et al., 2009; Malina et al., 2000). Contrasting results were observed in Japanese youth. The only group that showed significant bias was the U-13 age group where the proportion of early maturers was 58% compared to 20% and 18% in the U-12 and U-14 grades respectively (Hirose & Hirano, 2012). It was proposed in both studies that the reason for this could be that in Japan elite adult level (J-League) clubs recruit players from the age of 13. Hence why players still in academies outside of the elite J-League are likely to be on-time or late maturers (Hirose, 2009).

Two studies on AFL populations reported their findings in terms of the APHV of selected and non-selected players (Toum et al., 2020; Tribolet et al., 2018). A significant but small effect was observed, selected players had a younger APHV than non-selected players, 13.8±0.4 and 14.1±0.7 ($p=0.047$, ES=0.06) respectively (Toum et al., 2020). Similarly in the second study selected players also had a younger APHV compared to non-selected players, 13.8 ±0.6 and 14.3 ± 0.6 ($p<0.05$) respectively (Tribolet et al., 2018). Furthermore, the APHV of 619 ice hockey players selected for a U-15 Canadian provincial team was lower than non-selected players but both groups of players had very similar CA in decimal years of 14.73 and 14.60. Selected players had an average APHV of 12.81 yrs ±0.27 and non-selected players had an APHV of 13.48 yrs ±0.64 ($p<0.05$) (Sherar et al., 2007). A study examining elite level youth tennis players reported contrasting findings to all the other studies reviewed. This is the only study to investigate an individual sport with all previous studies assessing team sports and the selection and/or retention of players in academy systems or elite teams. The top 8 male and female tennis players in the Great Britain National Rankings in the age groups (U-10 to U-18) were observed. Selection bias was reported in terms of maturity timing for age groups of U-10, U-12, U-14 and U-16. In the male sample 32% were classified as early, 57% as on-time and 11% were late. For the females the overall sample classified 30% as early, 66% as on-time and 5% as late. Maturity offset was calculated with females having offsets ranging from (0.30 to 0.89 years) whilst males had a greater variation of maturity offset (-0.41 to 1.23). The underrepresentation of late maturers and maturity offset scores of < 1, excluding U-14 males, indicates a bias towards more mature players but not necessarily early maturing players (Myburgh et al., 2016).

A further study assessed the APHV of 870 Saskatchewan (Canadian province) youth aged from 11-17 in hockey, basketball, American football, baseball, soccer and volleyball. There was no significant difference in CA between selected and non-selected hockey players yet selected players had an average APHV of 0.2 years younger than non-selected players ($p<0.05$). Selected basketball players we significantly older (CA +0.5 years) yet they had significantly younger APHV of 0.5 years ($p<0.05$). American footballers had similar findings to hockey with selected players being significantly older (CA +0.3 years) and having a younger APHV of 0.4 years. Selected and non-selected baseball players had no significant difference in CA and a younger APHV of 0.4 years. Selected soccer players also had a younger APHV of 0.4 years compared to non-selected players (Baxter-Jones et al., 2020).

Across all the sports observed within the reviewed studies each sport identified a selection bias towards more mature players at either one or multiple age groups. The magnitude of the selection bias varied across all sports. The strongest and most consistent evidence of a maturation selection bias is in football. This could be attributed to football being a more widely researched sport due to the popularity and early age of team selection. Differences between sports may also reflect the differing physical demands between sports.

2.2.4 Selection Bias in Males versus Females

From the 13 studies selected for review only 2 studies (Baxter-Jones et al., 2020; Myburgh et al., 2016) included females in the study population. This reveals a lack of evidence in female populations and raises the concern that practitioners may be unaware of the potential maturation selection bias in female sport. Research in the female youth population is lacking and there is a clear need for further studies. From the studies reviewed, there were significant differences observed between many of the sports. In a female population in hockey, basketball, soccer and volleyball teams there was no significant difference in APHV in selected and deselected players. Therefore, no selection bias was present. In the male teams participating in the same sports there was a selection bias towards more mature players in hockey, basketball, and volleyball (Baxter-Jones et al., 2020). Assessing the APHV of elite male and female youth tennis players indicates that at the younger age group (U-10) males had a negative maturity offset (-0.41) whilst females had a positive one (0.78). This could be due to females on average maturing at a younger age (11) than males (13), resulting in maturity based physical performance enhancements at a younger age. As CA increases the female maturity offset reduces to (0.39 and 0.30) in the U-12 and U-14 age groups. For males in the same age groups the maturity offset increases to 0.09 and 1.23 respectively. These results suggest that a selection bias exists in females at the age of 10-11 whilst it occurs at an older age in males 13-14 (Myburgh et al., 2016). As females mature their physical capacity does not increase to the same extent of males. VO_2 max is similar between males and females relative to body mass pre-PHV. In the circa-PHV stage males VO_2 max increase at a greater rate than females. Approximately 13% difference at 10 years, 17% difference at 13 years and 23% difference at 16 years (Armstrong & Welsman, 1994; Zwiren, 1989). Males VO_2 max continues to increase until the age of 17 whereas females' plateau around the age of 13 (Kemper et al., 1989). Strength gains for females occur at approximately 11-13 years of age and then plateau whereas in males' strength gains accelerate at 12-13 yeas and continue to increase throughout maturation until post-PHV (Roemmich & Rogol, 1995). The influence of strength capabilities and stature can be identified as desirable or not dependant on the sport/movement in question. For many sports it is seen to be beneficial if an individual possesses greater, strength, power and/or stature. However, in the case of certain sports like artistic gymnastics there are specific roles within the group suited to smaller, lighter individuals. This is because they can rotate faster and are easier to project into the air for certain movements (Malina et al., 2006, 2013). Therefore, maturity related physical enhancements and maturation selection bias are dependent on the sport and movements performed. Overall, based on the limited available evidence, the selection bias is not as prevalent in females compared to males.

2.2.5 Limitations in the evidence reviewed

Limitations were noted in many of the studies reviewed. Seven of the studies acknowledged they were limited by small sample size, indicating the sample size was insufficient to provide generalizable findings for their study population. The largest sample size from the studies reviewed observed 870 athletes (Baxter-Jones et al., 2020). This is important as when the findings from each sport are collated the findings are generalisable for a wide range of sports across varying age groups of males and females. However, once the study participants were grouped by gender, age, and sport many of the specific sample groups were too small to provide clear group differences in APHV in selected and non-selected players. Several studies amalgamated age cohorts together to increase the sample size for statistical analyses of a specific population. For example, the amalgamation of U-13 and U-14 players to form one sample group of U-14 players allowing clear differences in the APHV to be reported between selected and non-selected players. However, it was highlighted that combining age groups may ignore age-related variation in maturity and can lead to results being misinterpreted due to the increased maturity variability (Toum et al., 2020; Tribolet et al., 2018).

Furthermore, another significant limitation was the representativeness of the sample populations. Much like sample size, many studies agreed that the findings produced were only representative of their specific population and the findings are not generalizable to other sports, ethnicities, and age groups. For example, within a Japanese youth football population with findings suggesting a selection bias towards more mature players is only evident in the U-13 age group (Hirose and Hirano, 2012). Meanwhile in an English youth football population of the same age it was observed that an increase in selection bias favouring more mature players from the U-14 age group onwards. These results show that within the same age group results can significantly vary dependant on the ethnicity and ability of the players observed. The magnitude of the selection bias highlighted the variability between sports with youth of the same ethnicity. Further, confirming the idea that results are not generalizable beyond the specific population in question (Baxter-Jones et al., 2020).

Lastly, the maturation prediction equations and reference populations have limitations depending on the study sample population. Several studies (Hill et al., 2020; Figueiredo et al., 2009; Johnson et al., 2017) used previously validated reference data from the longitudinal Berkeley Growth Study (Bayer & Bailey, 1959) and Fels Longitudinal Study (Roche et al., 1988). The reference data was based on samples of European Caucasian ancestry from Ohio and California (United States). Both English football academy studies (Hill et al., 2020; Johnson et al., 2017) samples consisted of predominantly European Caucasians. However, the study observing Portuguese youth footballers compared their population with American youth (Ohio & California) reference data. This may have reduced the accuracy in the maturation assessment (Figueiredo et al., 2009). These differences in reference and sample population can result in poor estimation of maturation due to ethnic diversity. One study identified the discrepancy between reference data (TW) and modified Japanese standardized skeletal age (J-SA) reference values. Japanese youth reached adult Radius-Ulna-Short bone (RUS) scores of the Tanner-Whitehouse 2 (TW2) method, 1-2 years earlier than European children (Hirose & Hirano, 2012). At ages younger than 12, Japanese youth scored lower (RUS) than European children by approximately 2 years. From 12 years of age onwards the RUS was advanced in comparison to European children (Ashizawa et al., 1996). Applying a modified maturation assessment calculation, Tanner-Whitehouse 3 (TW3) that used English, American, and Japanese data resulted in better accuracy of maturation classification. These findings highlight the potential to under and overestimate biological maturity when using reference data that is not representative of the sample population.

Only two studies used reference data that was well matched for ethnicity and reasonably recent (Baxter-Jones et al., 2020; Myburgh et al., 2016).

2.2.6 Conclusion

Most of the studies reviewed identified a selection bias towards more mature players across a variety of age groups, different sports and genders. The extent of the selection bias was variable across the sports reviewed. Football provides the strongest evidence across a variety of age-groups and environments. Common findings between the studies revealed more mature players were selected over less mature players. This was evidenced by reports of selected players having a younger APHV than non-selected players, players at a higher playing level having a greater SA and similar CA and elite level training/academy groups having an over-representation of more mature players and underrepresentation of less mature players. Findings from the studies comparing age groups of observing elite training/academy groups identified that the magnitude of selection bias towards more mature players increase as chronological age increases.

Between males and females, a significant difference in selection bias were observed. Regardless of the sport it was evident a selection bias favouring more mature players was only present in males from the age of U-13 onwards (Baxter-Jones et al., 2020; Myburgh et al., 2016). Females displayed no significant difference in APHV between selected and non-selected players at any age (Baxter-Jones et al., 2020). The comparison between youth males and females of the same sport within the same population has not been widely studied and this is an area requiring further research.

Prelude to Chapter 3

The literature review in chapter 2 highlighted that maturity based selection bias is common in youth sport. There is a lack of evidence as to whether or not this bias exists in youth sport in New Zealand. Key findings from the review identified that there is often a selection bias towards more mature players in youth sports teams, but there are likely differences between sports and differences between males and females. Therefore, more evidence focusing on youth sport team selection across a variety of sporting codes and gender is needed.

Thus, chapter 3 reports on a cross-sectional study, conducted to examine any current maturity selection bias in secondary school academy sports teams in a NZ secondary school. Recent history of injury was also collected to investigate any link between maturity status and injury in this group.

Chapter 3: Maturation Selection Bias and Injury in Secondary School Sports Academy Teams: A Cross-Sectional Study

3.1 Overview

The aim of this study was to examine maturation selection bias and injury in a secondary school sports academy. Male students (n=98) from a Boys High School had their anthropometric measurements taken (standing height, seated height, and weight). Estimated percent of predicted adult height (%PAH) was derived from these anthropometric measures using the Khamis-Roche method. Percent of PAH was then used to estimate maturity status and timing. Participants also completed an injury history survey designed to understand the nature of any injuries experienced over the previous three months. The majority of participants were early maturers (65.3%, n=64), suggesting a bias towards the selection of more mature players. Late maturers accounted for only 1% (n=1) of players selected. Injury history survey identified that 60% (n=52) of participants had been injured in the three months prior to data collection but there was no association with maturity status. Increased awareness of the potential for maturity based selection bias in secondary school team sports is needed.

3.2 Introduction

Youth sport is popular around the world, with New Zealand being no exception. Ninety four percent of Youth in New Zealand (5-17 years of age) participate in sport and recreational activities (Sport New Zealand - Active NZ 2018 Participation Report, 2019). Many oversees countries have similar participation rates, such as Canada, with 76% of youth aged 11-15 participating in sporting activities (ParticipACTION Canada 2018).

It is generally accepted the primary reason younger children (ages of 5-10 years) participate in sport is because it is fun, and they enjoy it (Visek et al., 2015). However, as young children move towards and into adolescence, sporting goals and reasons for playing sport often change. While fun is still a factor, performance orientated goals relating to team selection and skill enhancement become more important (Ingrell et al., 2019, 2020). In many environments' sport team selection based on ability can occur at a very young age, with trials for premier teams beginning from as young as nine years old (Read et al., 2016; Sweeney et al., 2021). It is generally acknowledged that in team selection during adolescence, coaches select players that possess greater physical capabilities and subsequently better athletic performance (Patel et al., 2019). As a result, many authors have identified that biological maturation must be factored in when selecting youth for sports teams to avoid the potential for inappropriate early deselection of late maturers (Figueiredo et al., 2009; Hill et al., 2020; Johnson et al., 2017; Philippaerts et al., 2006). This can potentially result in talented young people not being retained in sport and/or late maturers dropping out because they are being told they are not good enough. This leads to an ineffective selection system as increased physical capabilities are correlated to biological maturation and are thought to have minimal impact on performance differences once players fully mature (Cumming et al., 2018; Gibbs et al., 2012). Thus, an understanding of maturity and biological growth is important when selecting adolescents to ability-based sports teams.

An awareness of maturational status is also important to help reduce injury risk. Injuries are a concern in youth sport as injuries can negatively impact long term athlete development (LTAD). Previous research suggests there are periods of time during maturation where players are more susceptible to injury (Bahr & Krosshaug, 2005). The highest rate of injuries has been reported during the period of peak height velocity (PHV), potentially due to rapid anthropometrical, neuromuscular, and structural changes (Bult et al., 2018; Johnson et al., 2019; van der Sluis et al., 2014). In relative terms circa-PHV players have been observed to experience the greatest number of injuries per 1000 player hours, (24.5/1000h) compared to pre-PHV (10.7-11.5/1000h) and post-PHV (16.4/1000h) players (Johnson et al., 2019). The severity and burden of injuries has also been shown to vary across maturation (Bult et al., 2018). As the risk, severity and burden of injuries changes, monitoring maturation allows training to be adapted to reduce injury risk. This field of research is ever-growing and fundamental in understanding how to adequately load youth athletes to promote physiological development whilst reducing the risk of overuse and acute injuries and enhancing communication around growth and maturity between players, parents, and coaches (Salter et al., 2021).

Maturity estimation based on anthropometric measurements is widely used in youth sport settings. A common estimation is the Khamis-Roche method (Khamis and Roche, 1994). The Khamis-Roche method estimates maturity status and timing based on date of birth, height, weight and mid-parent height measurements used to estimate percentage of predicted adult height (%PAH). Percent of PAH can then be used to estimate maturity status - pre, circa or post PHV and maturity timing (early, on-time or late maturing).

To date there is little evidence in youth sport in New Zealand regarding potential maturity related selection bias in secondary school sport nor the association between maturity and injury history. Thus, the aims of this research were to investigate (i) the maturity status of players selected to a performance-based sport academy and (ii) the association between maturity and injury history.

3.3 Methods

3.3.1 Study Participants

Ninety-eight males in school years 9 and 10 selected for premier youth sports teams at a Boys high school were recruited to participate in this study. Prior to participation, all participants, parents, and coaches were informed of the purpose, benefits and risks of this study before completing the consent and assent forms. Ethical approval was given for the study by the Auckland University of Technology Ethics Committee (#22/47).

3.3.2 Biological Maturity Estimation

To estimate biological maturity status and timing, anthropometric data including standing height, weight and seated height was recorded for all participants. Height was measured with a stadiometer and weight with standard scales. Additionally, the participants biological parents were asked to provide an estimate of their height. Maturity status estimations were collected by applying %PAH bands. Participants with a %PAH less than 88% were categorised as pre-PHV. A %PAH between 88% and 93% circa-PHV and greater than 93% as post-PHV (Cumming et al., 2017; Salter et al., 2022; Sander et al., 2017). Maturity timing estimations were calculated by applying %PAH z-scores (Hill et al., 2020). Two criteria were used to estimate maturity timing. Participants with z-scores of -0.5 to +0.5 were categorised as on-time; a z-score greater than +0.5 was categorised as early and below -0.5 as late. A more conservative criterion was also applied where z-scores of -1.0 to +1.0 were categorised as on-time; a z-score greater than +1.0 was categorised as early and below -1.0 as late. %PAH z-scores were derived from the reference data from the longitudinal Berkley Growth Study (Bayer & Bayley, 1959).

3.3.3 Injury data collection

A face-to-face paper-based questionnaire was used to capture injury history over the previous 3 months. The questionnaire was designed to capture injuries from youth participants and has been reported previously (McGowan et al., 2020). Participants were asked if they had sustained any sport-related injuries during the past 3 months. For every participant who answered yes, the researcher spoke to them and verified the location and type (acute or gradual onset) of each injury. Acute injuries were defined as a sudden pain that occurred as the result of a sudden identifiable event. Gradual onset injuries were defined as any physical complaint not induced by a single sudden event and could include both overuse problems and growth-related problems. All injuries were recorded, whether time was lost from sport or not.

3.3.4 Data Analysis

Descriptive statistics were used to examine the extent of any selection bias towards early maturing players (proportion of participants in each category) and summarise the survey responses to the injury history questions (percentage of participants with an injury). A one-sampled means *t*-tests was used to examine the degree to which biological maturation bias existed across the total sample by comparing the observed mean z-score value against the value expected for the general population maturity *Z*-score = 0.0). Results are presented as z-score mean difference and effect size (Cohens D ±95% confidence interval). Effect size magnitude was interpreted based on the following scale (small = 0.2–0.49; moderate = 0.5–0.79; large = 0.8–1.49; very large ≥ 1.5). Additionally, a Chi-square test was used to analyse the expected proportion of early, on-time and late maturers relative to what could be expected based on a normal distribution. Based on the most commonly used criterion (z-score ±1.0), the expected frequency of early maturing players (z score > 1.0) and late maturing players (z score < 1.0), in a normally distributed population, would be 15.7 (16% of the 98 participants) and the expected frequency of on-time players would be 66.6 (68% of the 98 participants). Results are presented as observed vs expected frequency for maturity timing. Additionally, an independent samples t-test was used to compare mean height and weight between early and on-time/late participants. Results are presented as mean difference and 95% confidence interval. Finally, logistic regression was used to investigate the association between injury history and maturity status (pre, circa, post-PHV). Results are presented as unadjusted odd ratios with 95% confidence intervals. The threshold for statistical significance was set at $p < 0.05$.

3.4 Results

3.4.1 Participant Information

A total of ninety-eight male sports academy students from a boys high school junior sports academy participated in this study. Descriptive statistics identifying chronological age (CA), %PAH and %PAH z-score for the full sample of participants are reported in Table 2. The CA range of the participants was 13.0 to 15.2 years, mean age 14.1 years. Estimated maturity status, expressed as %PAH, suggested participants on average were post-PHV (mean %PAH = 93.1). Estimated maturity timing (%PAH expressed as z-scores) was on average positive (mean z-score = 0.72). This was significantly greater ($p<0.05$) than expected in the general population (z-score = 0.0), effect size for difference in mean z-score = 1.2 (95% CI = 0.93 to 1.4), suggesting a large bias.

Table 2. Descriptive statistics for chronological age (CA), percentage of predicted adult height (%PAH), maturity timing (%PAH z-score)

Variables	Mean ±SD	Range
CA (yrs)	14.1 ± 0.6	13 – 15.2
% PAH	93.1 ± 3.2	85.8 – 101.4
% PAH z-score	0.7 ± 0.6*	-0.6 – 2.8

*Significantly greater (t=11.7; p<0.05) than expected mean value for general population (z-score = 0.0)

Maturity status estimation is presented in Table 3. Results indicate that post-PHV participants accounted for 57.2% (*n* = 56) of the full sample population. When categorised by sport the post-PHV classification ranged from 21.4% (*n* = 3) in hockey to 68.2% (*n* = 15) in basketball.

Table 3. Distribution of academy players by maturity status

	Maturity Status (%PAH)		
	Pre (<88%)	Circa (88 to 93%)	Post (>93%)
Full Sample (*n* = 98)	6.1 % (*n*=6)	36.7% (*n*=36)	57.2% (*n*=56)
Sport	Pre (<88%)	Circa (88% to 93%)	Post (>93%)
Basketball (*n* = 22)	0% (*n*=0)	31.8% (*n*=7)	68.2% (*n*=15)
Cricket (*n* = 7)	14.3% (*n*=1)	0 % (*n*=0)	85.7% (*n*=6)
Football (*n* = 24)	12.5% (*n*=3)	25% (*n*=6)	62.5% (*n*=15)
Hockey (*n* = 14)	7.2% (*n*=1)	71.4% (*n*=10)	21.4% (*n*=3)
Rowing (*n* = 18)	0% (*n*=0)	33.3% (*n*=6)	66.7% (*n*=12)
Rugby (*n* = 13)	15.4% (*n*=2)	46.1% (*n*=6)	38.5% (*n*=5)

Maturity timing estimation using the less conservative criterion (z-score ±0.5) is presented in Table 4. The majority of players (65.3%) were classified as early maturers. On-time and late maturers accounted for 33.7% and 1% of the sample respectively. Applying the more commonly used but more conservative criterion (z-score ±1.0), 34.7% of participants were classified as early maturers and the majority of the participants (65.3%) were classified as on-time, with no late maturers (Table 5). Based on the less conservative criterion the proportion of early maturers across sports ranged from a high of 88.9% (rowing) to a low of 28.6% (hockey), while this range is 61.1% (rowing) to 14.3% (cricket) using the more conservative criterion. Results of the Chi-square analysis show a significant difference (p<0.001) between the observed and expected frequencies of early, on-time and late maturers, based on the more commonly used criterion (z-score ±1.0), (Table 6).

Table 4. Distribution of academy players by maturity timing (z-score ±0.5)

	Maturity Timing*		
Age Group	Late	On-time	Early
Full Sample (*n* = 98)	1.0% (*n*=1)	33.7% (*n*=33)	65.3% (*n*=64)
13-13.9 (*n* = 43)	2.3% (*n*=1)	46.5% (*n*=20)	51.2% (*n*=22)
14-14.9 (*n* = 46)	0% (*n*=0)	23.9% (*n*=11)	76.1% (*n*=35)
15-16 (*n* = 9)	0% (*n*=0)	22.2% (*n*=2)	77.8% (*n*=7)
Sport	Late	On-time	Early
Basketball (*n* = 22)	0% (*n*=0)	27.3% (*n*=6)	72.7% (*n*=16)
Cricket (*n* = 7)	0% (*n*=0)	28.6 % (*n*=2)	71.4 (*n*=5)
Football (*n* = 24)	4.2% (*n*=1)	29.2% (*n*=7)	66.6% (*n*=16)
Hockey (*n* = 14)	0% (*n*=0)	71.4% (*n*=10)	28.6% (*n*=4)
Rowing (*n* = 18)	0% (*n*=0)	11.1% (*n*=2)	88.9% (*n*=16)
Rugby (*n* = 13)	0% (*n*=0)	46.1% (*n*=6)	53.9% (*n*=7)

*On-time = z-score ±0.5, Late = z-score < 0.5, Early = z score >0.5

Table 5. Distribution of academy players by maturity timing (z-score ±1.0)

	Maturity Timing*		
Age Group	Late	On-time	Early
Full Sample (*n* = 98)	0 % (*n*=0)	65.3% (*n*=64)	34.7% (*n*=34)
13-13.9 (*n* = 43)	0% (*n*=0)	62.8% (*n*=27)	37.2% (*n*=16)
14-14.9 (*n* = 46)	2.1% (*n*=1)	63.8% (*n*=30)	34.1% (*n*=16)
15-16 (*n* = 9)	0% (*n*=0)	77.8% (*n*=7)	22.2% (*n*=2)
Sport	Late	On-time	Early
Basketball (*n* = 22)	0% (*n*=0)	63.6% (*n*=14)	36.4% (*n*=8)
Cricket (*n* = 7)	0% (*n*=0)	85.7 % (*n*=6)	14.3% (*n*=1)
Football (*n* = 24)	0% (*n*=0)	66.7% (*n*=16)	33.3% (*n*=8)
Hockey (*n* = 14)	0% (*n*=0)	78.6% (*n*=11)	21.4% (*n*=3)
Rowing (*n* = 18)	0% (*n*=0)	38.9% (*n*=7)	61.1 % (*n*=11)
Rugby (*n* = 13)	0% (*n*=0)	76.9% (*n*=10)	23.1% (*n*=3)

*On-time = z-score ±1.0, Late = z-score < 1.0, Early = z score >1.0

Table 6. Observed versus expected frequency of early, on-time and late maturers

	Timing z-score (±1.0)	
	Observed (n)*	Expected (n)
Early	34	15.7
On-time	64	66.6
Late	0	15.7

* significantly difference from expected (chi-square = 15.6 ; p<0.001)

The mean height of early maturers was significantly greater than on-time/late maturers (mean diff = 11.5cm; 95% CI = 8.0 to 14.9cm; p<0.001). The mean weight was also significantly greater (mean diff = 13.6 kg; 95% CI = 8.1 to 19.0kg; p<0.001).

Eighty-seven participants provided information on their recent injury history with 60% (n=52) reporting an injury in the previous 3 months (38% acute injuries and 62% overuse injuries). The most common injury locations were the knee (29%) and ankle (17%). There was no significant association between injury history and maturity status (note pre-PHV not included due to small n) (Table 7).

Table 7. Injury history in circa and post-PHV participants

	Circa	Post	Unadjusted OR (95% CI)	P value
History any Injury (%)	58	61	1.16 (0.48 - 2.79)	0.74
History overuse Injury (%)	39	35	0.84 (0.34 - 2.04)	0.69
History acute injury (%)	19	26	1.56 (0.54 - 4.6)	0.41

3.5 Discussion

Findings from this study investigating the growth and maturation of boys in a sports academy at a boy's high school identified a bias towards more mature players. When maturity timing was classified using the less conservative criterion (z-scores of ±0.5) a clear bias favouring early maturing players was observed. Using this criterion, the bias became more evident in the 14-year age group (76% early maturers) compared to the 13 year age group (51% early maturers). The data suggest that, with age and the assumption of an additional year in the sport, boys advanced in maturity (early maturing) are selected in greater proportions. Applying the more conservative maturity timing criterion (z-scores of ±1.0) the bias favouring more maturing players remained however it wasn't as strong, with approximately 60% of players in the 13- and 14-year age group classified as on-time. Irrespective of the criterion used, the percentage of late maturing players did not exceed 1% of the whole sample, further suggesting a maturity-based selection bias.

Favouring more mature players during the time of team selection tends to be due to the increase in physical size and the associated enhanced performance capabilities. Increased physical performance capabilities are commonly observed when comparing youth athletes of greater biological maturity to less mature athletes of the same chronological age. For example, increased muscle mass is often attributed to greater strength, sprint, change of direction and jump performance (Hammami et al., 2016; John et al., 2019 & Philippaerts et al., 2006). However, these maturity-related enhancements do not continue into adulthood and may inappropriately result in less mature players being deselected (Helsen et al., 2005; Hirose, 2009: Vaeyens et al., 2005). Furthermore, sporting performance is not solely dictated by physical characteristics, but rather a combination of physical performance capability, technical competency, tactical awareness, and game understanding (Sheppard et al., 2006). Sports teams are at risk of losing late maturing players who often display and/or develop more advanced technical, tactical and psychological skills compared to their more mature counterparts. This is thought to be one of the ways that late maturing players are able to compete with the rest of their playing cohort (Cumming et al., 2018).

The findings from the current study agree with several previous studies that have also reported a maturity-based selection bias in youth sport (Hill et al., 2020; Johnson et al., 2017; Malina et al., 2000; Ostoijic et al., 2014). The average age of PHV in male youth is approximately 14 years of age (Aksglaede et al., 2008; Malina & Koziel, 2014). This is the period that is also when more mature players dominate their less mature counterparts. Previous studies have reported that the 13 and 14 year age groups are dominated by more mature players (early maturers) (Hill et al., 2020; Johnson et al., 2017; Hirose, 2009)., with maturity selection bias becoming more prominent in the age groups from 13 years of age onwards (Hill et al., 2020; Johnson et al., 2017; Hirose, 2009). It should be noted that the majority of players (65.3%) in the current study were classified as "early" using the less conservative maturity timing criterion (z-score ±0.5). Much like the findings from Hill et al., (2020), when applying the more conservative maturity timing criterion (z-score ±1.0) the bias was no longer favouring early maturing players, rather that on-time players represented the greatest portion of the cohort (65.3%) with 34.7% and 0% of players classified at early and late respectively. Comparing these findings to what was expected, the results are closely aligned to what was expected to be observed for the on-time cohort (observed n = 64, expected n = 66.6). The bias is only observed when comparing the proportion of players classified as early or late. The overrepresentation of early (observed n = 34, expected n = 15.7) and underrepresentation of late (observed n = 0, expected n = 15.7) maturers indicates that more mature players are still favoured over less mature players. As several authors investigating elite football academies have suggested, the underrepresentation of late maturing and pre-PHV players in academy systems is a cause for concern. When late maturing players are selected or retained in academy systems or elite youth teams where the majority of players are more mature than them, they are often seen as the underdog. The underdog hypothesis stems from the idea that to become and/or stay competitive less/late maturing players must possess and/or develop more advanced technical, tactical and psychological skills. The skill and knowledge gained during this period is thought to remain into adulthood whereas early maturing players physical advantages subside in adulthood (Cumming et al., 2018; Gibbs et al., 2012).

Maturity status classifications for the players in the current study (average age 14 years) further highlights the disproportionate representation of pre, circa and post-PHV players in the sport academy system. Post-PHV players accounted for 57.2% of the population followed by circa and pre-PHV players, 36.7% and 6.1% respectively. Given the average age of the players we might have expected more of the players to be circa-PHV and pre-PHV.

The current study investigated the potential maturity selection bias across a range of sports. Although formal comparisons weren't undertaken (due to small numbers), the different sports displayed varying proportions across the maturity classification. It has been reported previously that in a population of 868 Saskatchewan (Canada) youth that some sports displayed a bias towards more mature players and some did not. In the 14-year age group hockey and basketball teams were observed to have more mature players selected. This was indicated by the average chronological age and the average age of PHV (APHV). Hockey = 14.6 and 13.4 respectively and basketball = 14.7 and 13.1 respectively. In contrast to these findings were the soccer (football) population. Selected players had a very similar average age and average APHV (14.2 and 14.1 respectively). This shows hockey and basketball had greater proportion of players who were more mature than soccer (Baxter-Jones et al., 2020). These findings indicate that the physical sporting requirements of each sport can influence player selection due to perceived ability and maturity-related physical advantages. For example, elite youth rowers have been observed to be taller and heavier than sub-elite and reference populations (Yoshiga & Higuchi, 2003) with the stature of elite youth rowers similar to elite adult rowers (Bourgois et al., 2000). Similarly, findings from the current study agree with a study of elite Portuguese football players (Malina et al., 2000). Early maturing players were on average, taller (mean difference = 11.5cm; 95% CI = 8.0 to 14.9cm; $p<0.001$) and heavier (mean difference = 13.6 kg; 95% CI = 8.1 to 19.0kg; $p<0.001$) than the on-time/late maturing players. Observed and expected rowing ability is strongly associated with height and weight in youth elite rowers (Burgois et al., 2000). Maturity-related enhancements in field sports such as football and hockey appear to not be as strongly associated to team selection as rowing. This could be due to the sports having additional performance indicators such as sprint, COD and jumping ability as well as tactical game awareness (Bangsbo, 2014; Meylan et al., 2010; Mohr et al., 2003).

Although this study did not identify any clear association between maturity status and injury, our findings suggest that there is a considerable proportion of players in circa-PHV (58%) and post-PHV (61%) who experienced injury within the three months prior to data collection. This raises concern as to whether the nature of the training and competition is appropriate for this period of development. Within the post-PHV cohort of players 26% experienced acute injuries. Acute injuries commonly result in extended periods of time loss where the players cannot train or compete to their full capacity (DiFiori et al., 2014; Ritzer et al., 2021). Several researchers have observed increased injury rates and severity in academies and elite teams. Findings suggest that the more mature players experience injuries of greater trauma and severity at a higher rate than less mature players (Le Gall et al., 2007: Materne et al., 2021; Monasterio et al., 2021)

There are several limitations to this study that should be stated. Firstly, the results are specific to a boy's high school academy system in the six key sports that had a recognised academy system within the school. Additionally given the differences in biological maturation for young females there is a need to investigate selection in secondary school female sport. The results may not be generalizable to other countries, schools, clubs, and academy systems. Although maturity-based selection bias is likely to differ by sport our sample size in each sport did not allow use to make any clear conclusions regarding these differences. The methods used for the maturity estimation incorporated self-reported biological parent heights and the reference values used to derive z-scores were from European participants in America which may not be representative of the local population. Finally, injury history data was solely based on participant recall and although it was over a short time period (3 months) it is susceptible to recall bias.

3.6 Conclusion

The main aim of this study was to examine maturation selection bias in a secondary school sports academy. A clear bias toward earlier maturing boys was found, with some indication this differed by sport. There were no clear associations between maturity status and recent history of injury, however a large proportion of this adolescent population reported some injury in the last 3 months. These findings suggest the need for selection processes that better acknowledge differences in maturity to avoid the loss of late maturing boys and the need to prioritise injury prevention in this adolescent group.

Chapter 4: Discussion and Conclusion

4.1 Discussion

Sports participation amongst young children and youth is extremely popular with approximately 94% of young people (5-17 years) involved in sport or recreational activities in New Zealand (Sport New Zealand - Active NZ 2018 Participation Report, 2019). These high participation rates are often attributed to the enjoyment the participants get when taking part in sports with their peers. As youth grow older the purpose of their participation often changes to align more with sporting goals of team selection as opposed to learning new sports and skills in a recreational environment (Ingrell et al., 2019, 2020). Coinciding with this change in sporting motivation that is more focused on sporting goals, youth also enter a time where there is more exposure to ability-based trials for premier sports teams. These trials have been reported to occur at ages as young as nine years of age (Read et al., 2016; Sweeney et al., 2021). In these selection trials concern has been expressed selection is biased towards more mature (often bigger) players due to temporary advantages in physical capability linked to athletic performance (Sheppard et al., 2006). As there is considerable variation in the timing and rate of growth and maturation during adolescence this is thought to significantly impact team selection. The period of the adolescent growth spurt is also a time where injury risk can increase, and this is an additional reason why maturity status and timing need to be considered in youth sport.

There is limited research investigating maturity selection bias in academy systems across a variety of sports, particularly within in New Zealand. The purpose of many academy systems is to develop athletes to create the most successful senior team possible (Johnson et al., 2017). The development of technical, tactical, physical, functional and psychological skills are all linked to the theory of long-term athlete development (Reilly et al., 2000). Therefore, this dissertation aimed to investigate the maturation selection bias in a secondary school sports academy and secondarily to investigate if maturity status was linked to recent injury history.

Previous research investigating the issue of maturation based selection bias has primarily been in boys football within the United Kingdom population. Observations from several studies have found that in youth sport, academy systems or elite teams commonly have a bias towards selecting more mature players (Chapter 2). Evidence suggests this can occur at ages as young as 12 years old (Figueiredo et al., 2009; Johnson et al., 2017), with the greatest impact occurring around the age of 14, the age coinciding with the expected age of PHV in the general population of boys. (Aksglaede et al., 2008; Malina & Koziel, 2014). A maturity based selection bias results in a disproportionate distribution of early, on-time and late maturing players in these academy systems and elite junior teams. Exclusion of the late maturing players can reduce the talent pool for future selection at adult level. It is thought that late maturing players who are retained in the academies and elite junior teams possess and/or develop more advanced technical, tactical and psychological skills (Cumming et al., 2018; Gibbs et al., 2012).

This dissertation offers new understanding and raises awareness around maturity-based selection bias and insights into injury in boys secondary school academy systems in New Zealand. In general, this study identified that there was a bias towards the selection of more mature players, in agreement with previous research (Baxter-Jones et al., 2020; Hill et al., 2020; Johnson et al., 2017; Myburgh et al., 2016; Sherar et al., 2007; Toum et al., 2020). Compared to the general population the mean %PAH z-score was significantly greater than expected, suggesting a large bias (ES = 1.2, 95% CI = 0.93 to 1.4). Regardless of the maturity timing criterion applied during analysis there was a significant underrepresentation of late maturing players (1% of the entire sample). Additionally, there was two to four times more early maturers than expected depending on the criterion used.

A critical observation from the current study was the extremely underrepresented late maturing population. Previous authors have reported that this was an issue in several sports however the underrepresentation of later maturers was not this severe in other studies of similar population sample sizes. With previous research commenting on how late maturers possess different advantageous over their more mature counterparts (Cumming et al., 2017: Gibbs et al., 2012) this suggests that coaches have minimal knowledge on how valuable these players can be to the team technically and tactically. If late maturing players are retained in the academy system, then it is thought they must possess and/or develop superior technical, tactical and psychological skills. This theory has been coined the underdog hypothesis (Gibbs et al., 2012). This hypothesis will only be observed if the late maturing players are selected/retain selection in the sport system throughout their youth into adulthood. The real word effects of the underdog hypothesis were investigated across four English professional football academy systems with athletes ages ranging from 11-16 years (Cumming et al., 2018). Results identified that within the academy system later maturing players reported greater engagement in self-regulated learning, evaluation, and reflection. This supports the idea that these adaptive learning skills may be the reason as to why these later maturers can compete with their physically bigger, faster, and stronger, more mature counterparts (Cumming et al., 2018).

Analysis of maturity selection bias across a range of sports has revealed there are several maturity influenced characteristics potentially associated to why players are selected in different sports. Previous research identified that elite youth rowers were taller and heavier than sub-elite youth rowers (Yoshiga & Higuchi, 2003). Similar findings from Portuguese football players showed early maturing players dominating selection and they were also taller and heavier (Maline et al., 2000). This explains why taller and heavier players are selected as they have anthropometric advantages corresponding to biomechanical enhancements (Bourgois et al., 2000).

There are numerous ways the maturity selection bias could potentially be addressed, and techniques applied to reduce the selection bias favouring more mature players. Some of the key factors to consider are education and awareness, maturity estimation and monitoring, team selection techniques and injury prevention measures.

The first steps to reducing maturity selection bias is to educate all of those who are involved with youth sport including, coaches, parents and players themselves. Educating and raising awareness around the concepts of physical and psychological development of youth will allow coaches to understand that all youth start to mature at different times and mature at different rates. Continuing to create awareness about the effect that maturity timing/rate has on performance and skill development across adolescence will help develop more efficient/effective selection and training practices. It is likely coach education should have greater focus on the theory around biological maturity and the changes youth experience (Malina et al., 2015). These key concepts and education tools can then also be passed on to parents and players. It is important youth understand how maturity status and timing can impact their experience in sport. Informing parents about maturation and how this can impact their children will allow them to better understand why performance may plateau circa-PHV, movements may become awkward, and their perception of physical ability may be misinformed. Lastly, raising awareness amongst the youth players is crucial as it will allow them to understand that they are all growing, and their bodies and minds will change as this happens. Creating environments where the players know they are supported and included will be fundamental in keeping youth in sport for the future. Strategies that could be implemented in a high school academy sport system include teaching theory related content during academy classes or general health and physical education classes. Students across many schools are already taught about how their bodies change in terms of sexual characteristics. Increasing awareness as to how these growth changes can influence how their bodies move will allow them to better understand their own experiences in sport.

As well as increased education and raising awareness around maturation, increased monitoring in schools could be useful. The key to understating and monitoring any changes in growth is to use the same estimation methods over time to provide consistent analysis over the duration of the athlete's time in the academy system. One way this could be implemented in a high school academy sport setting is during the physical performance testing battery that is often performed at the start of each year. This estimation early in the school year can provide the academy staff with appropriate information that may be able to help guide training programmes for the athletes. Using the first maturity estimation as a baseline for the year much like physical testing data. Follow up estimations part-way and/or at the end of the year can be used to track how the athlete has grown and any association this may have with their physical performance measures and/or sporting performance over the season. These measures can be used as guides to tailor training sessions for the varying maturity groups.

Once maturity estimations have been made, specific selection techniques could be trialled to try and reduce any maturity selection bias. A technique that is becoming more common in today's practices is bio-banding (Cumming et al., 2017; Malina et al., 2019). Bio-banding is the concept of grouping players by biological age or maturity timing/status rather than the traditional method of chronological age or school year level (Cumming et al., 2017). Similar methods such as weight restrictions have been implemented successfully in several combat and contact sports such as boxing and rugby respectively. The purpose of bio-banding is primarily to improve athlete safety and equity in the match/sport (Albuquerque et al., 2016). Bio-banding for maturity is commonly performed in two ways, either with maturity timing or status estimations. Applying maturity timing estimations for bio-banding result in early, on-time and late groupings of players, whereas maturity status leads to pre, circa and post-PHV groupings. The concept is the more mature players (early/post-PHV) would train and compete in their own group as would on-time/circa-PHV and less mature players (late/pre-PHV). Applying this technique can allow for the less mature players to have more opportunity to demonstrate their physical, tactical and technical skills and understand how they can use their bodies. For more mature players they can prepare themselves for competing at adult level against other more physically mature opposition and further make them use more tactical and technical skills as they no longer physically dominate their opposition (Cumming et al., 2017). Alternative techniques that have attempted to address maturity selection bias include age-ordered shirts in trials (Mann & van Ginneken, 2017) and average age teams (Verbeek et al., 2021). Due to the size of academy sport classes and resource constraints the bio-banding approach is likely to be most successful in a high school setting. In junior high school for example, years 9 and 10 (expected age range, 12-15 years) this method could be applied by combining both school year levels to create maturity specific teams. One way this could be applied is to estimate maturity at the beginning of the year, prior to season commencement. Identifying the more mature and less mature players, grouping them by maturity timing or status. More mature players can have trainings that are focussed on the development of tactical and technical elements of their sport that they can use as an advantage when competing against other players of similar maturity. Less mature players can have trainings focused on the development and/or utilisation of their skillset and learn how to use their body.

Lastly, the injury history data in the current study showed no clear association to maturity status. However, from the analysis it was clear that most players were injured in the three months prior to data collection. The contributing factors to the injuries such as player loading, rest periods, previous injuries were not accounted for nevertheless, the results showed that over half of the full sample experienced injuries in the past three months.

Due to the high percentage of injuries experienced by the players there are several strategies that could be considered to reduce the potential injury risk. The time of greatest concern for injury risk is circa-PHV (Bult et al., 2018; DiFiori et al., 2014; Materne et al., 2021; Read et al., 2018). Growth related injuries are common due to the rapid increases in long bone length, exceeding the growth rate of the associated muscles, tendons, and ligaments (Johnson et al., 2019; van der Sluis et al., 2014). Previous studies have recommended that when teaching skills to reduce the number of endless repetitions of the same movement/skill, to frequently alter the activities and provide rest periods, while monitoring for fatigue and incorporating rest/de-load weeks. Encouraging the exploration of new movements, sports and skills has also been suggested (Johnson, 2008). By monitoring maturity status team coaches and any additional staff such as strength and conditioning coaches can adapt training loads appropriately. Post-PHV players can focus on hypertrophy, developing strength and resistance to injury in commonly injured muscular sites such as the hamstrings and quadriceps (Materne et al., 2021; Monasterio et al., 2021; Price et al., 2006). Circa-PHV players commonly experience growth-related overuse injuries. In this group training load and intensity can be adapted to allow for adequate recovery and reduce the risk of these overuse injuries. (Johnson 2008). Neuromuscular training/warm-ups are another easily implemented strategy to reduce injury risk, especially during the circa-PHV period.

4.2 Limitations and Future Research Recommendations

The following limitations need to be considered when interpreting the results from this research. Due to the limitations and the main findings of this dissertation, key areas for future research have been identified.

- The main limitation to the study was the small overall sample size. This is due to the total number of players who are in the boys high school academy system. Future research should aim to increase the sample size possibly by working in several schools. This would allow investigation of any difference in maturity distribution by sport and playing level, which has been observed previously (Figueiredo et al., 2009).

- Only young males were included in the investigation. As young females often experience the onset of maturation earlier and to varying degrees than young males (Armstrong & Welsman, 1994; Roemmich & Rogol, 1995 & Zwiren, 1989). This is an area that needs to be investigated in future as previous authors have identified that maturity selection bias towards more mature players is present in a small range of sports (Baxter-Jones et al., 2020 & Myburgh et al., 2016).
- The thresholds for maturity estimation classifications need consideration. The less conservative criterion (z-scores ±0.5) is more capable of detecting potential maturity selection bias, however, this could increase type 1 error (detecting a bias when no such bias is present). Conversely the more conservative criterion (z-scores ±1.0) can limit the impact of maturity timing and could fail to differentiate considerable differences in maturity, resulting in the possibility of an increase type 2 error (not identifying a bias between individuals when there is a significant difference in maturity).
- The maturity status of boys was not known prior to their entry into the academy and thus it is possible the bias towards early-maturers was present prior to the academy selections.
- Lastly, a critical limitation that was relatively unavoidable was Covid-19. This limited the player participation due to illness and household isolations, contributing to the smaller sample size. Key areas for future research prospective gathering of injury data, assessment of player loading and coach understanding of LTAD and maturity. Injury history should be measured prospectively rather than retrospectively and account for the type of injury, location, mechanism, and days missed from full training or game participation. These factors will be able to provide a better understanding as to how injury is impacting the youth athletes. Player loading needs to be examined as this can influence many factors such as technical/tactical ability and injury. A player who is training four times per week and playing two games may improve their technical and tactical ability quicker than a player who is only training two times per week with one game. Associated to this is the increase in injury potential due to increased exposure due training and game time and reduced rest periods for those who have large training and game volumes. Lastly, assessing coach understanding in relation to LTAD and biological growth/maturity can help provide insight as to whether or not coaches are aware of the potential for maturity selection bias and ways that they can assist the development of late maturing players.

4.3 Practical Applications

Based on the key findings and recommendations of the research study (chapter 3), high school sports academy systems should consider the following practical applications regarding maturity selection bias.

- Educating coaches, parents and players about biological maturity and the influences this has on physical capabilities, skill development and cognitive decision making.
- Implementation of consistent maturity estimation throughout the school year. Estimating players biological maturity at the start of the school year during physical performance testing. Follow up estimations every 3-6 months where possible using the same estimation methods to provide consistency.
- Where practically feasible, implementation of bio-banded trainings and/or teams alongside traditional chronological/school year level teams.
- Where practically possible, engage in strategies to consider maturity status when selecting teams (e.g., bio-banding trials and/or matches and tournaments, average age teams, age numbered shirts, maturity classification specific trials).
- Utilise injury prevention measures applied by the academy strength and conditioning coach. Depending on the maturity status of the players adjust training loads where possible to reduce injury risk.

4.4 Conclusion

This dissertation consisted of an introduction/rationale, literature review, and one original study aimed at examining maturation selection bias and injury in a secondary school sports academy. This was the first study to investigate maturity selection bias in a high school sports academy system in New Zealand. There was a significant bias towards the selection of more mature players across the full sample population. While there were differences in the magnitude of the bias across different sports it was still present in all sports. This is cause for concern as this heavily reduces the selection of talent in the player pool at adulthood. Future research centred around the limitations and key observations raised in this dissertation is required to further understand the extent of the maturity selection bias and coaches understanding of maturity and perception on talent identification. This will help create environments that cater to all maturity groups and provide each individual with the specific tools and understanding required for their long-term athlete development.

References

Aksglaede, L., Olsen, L. W., Sørensen, T. I., & Juul, A. (2008). Forty years trends in timing of pubertal growth spurt in 157,000 Danish school children. *PloS one, 3*(7), e2728. https://doi.org/10.1371/journal.pone.0002728

Albuquerque, M.R., Fukuda, D.H., Costa, V.T., Lopes, M.C., & Franchini, E. (2016). Do weight categories prevent athletes from the relative age effect? a meta-analysis of combat sports. *Sport Sciences for Health, 12*(2), 133-139. https://doi.org/10.1007/s11332-016-0282-0

Armstrong, N. (2007). Paediatric Exercise Physiology. Advances in Sport and Exercise 188 Science Series, Churchill Livingstone Elsevier, Edinburgh, 2007.

Armstrong, N., & Welsman, J. R. (1994). Assessment and interpretation of aerobic fitness in children and adolescents. *Exercise and sport sciences reviews, 22*, 435–476.

Ashizawa, K., Asami, T., Anzo, M., Matsuo, N., Matsuoka, H., Murata, M., Ohtsuki, F., Satoh, M., Tanaka, T., Tatara, H., & Tsukagoshi, K. (1996). Standard RUS skeletal maturation of Tokyo children. *Annals of human biology, 23*(6), 457–469. https://doi.org/10.1080/03014469600004682

Bahr, R., & Krosshaug, T. (2005). Understanding injury mechanisms: a key component of preventing injuries in sport. *British journal of sports medicine, 39*(6), 324–329. https://doi.org/10.1136/bjsm.2005.018341

Balyi, I., Way, R., & Higgs, C. (2013). *Long-term Athlete Development*. Human Kinetics. https://us.humankinetics.com/products/long-term-athlete-development

Bangsbo, J. (2014). Physiological demands of football. *Sports Science Exchange, 27*(125), 1-6.

Baxter-Jones, A., Barbour-Tuck, E. N., Dale, D., Sherar, L. B., Knight, C. J., Cumming, S. P., Ferguson, L. J., Kowalski, K. C., & Humbert, M. L. (2020). The role of growth and maturation during adolescence on team-selection and short-term sports participation. *Annals of human biology, 47*(4), 316–323. https://doi.org/10.1080/03014460.2019.1707870

Bayer, L. M., & Bayley, N. (1959). Growth diagnosis: Selected methods for interpreting and predicting development from one year. Chicago, IL: Chicago University Press.

Bourgois, J., Claessens, A. L., Vrijens, J., Philippaerts, R., Van Renterghem, B., Thomis, M., Janssens, M., Loos, R., & Lefevre, J. (2000). Anthropometric characteristics of elite male junior rowers. *British journal of sports medicine, 34*(3), 213–217. https://doi.org/10.1136/bjsm.34.3.213

Bult, H. J., Barendrecht, M., & Tak, I. (2018). Injury Risk and Injury Burden Are Related to Age Group and Peak Height Velocity Among Talented Male Youth Soccer Players. *Orthopaedic journal of sports medicine, 6*(12), 2325967118811042. https://doi.org/10.1177/2325967118811042

Cavallo, F., Mohn, A., Chiarelli, F., & Giannini, C. (2021). Evaluation of Bone Age in Children: A Mini-Review. *Frontiers in pediatrics, 9*, 580314. https://doi.org/10.3389/fped.2021.580314

Chibane, S., Hautier, C., Gaudino, C. & Massarelli, R. & Mimouni, N. (2007). Influence of age, maturity and body dimensions on selection of under-17 Algerian soccer players. *Journal of Sports Science and Medicine. 10*(1). 62-65. https://doi.org/10.4324/9780203893685-32

Coelho-e-Silva, M., Figueiredo, A., Simões, F & Seabra, A., Natal, A & Vaeyens, R., Philippaerts, R., Cumming, S., & Malina, R. (2010). Discrimination of U-14 Soccer Players by Level and Position. *International journal of sports medicine. 31*(11). 790-796. https://doi.org/10.1055/s-0030-1263139.

Cumming, S., Lloyd, R., Oliver, J., Eisenmann, J., & Malina, R., (2017). Bio-banding in Sport: Applications to Competition, Talent Identification, and Strength and Conditioning of Youth Athletes. *Strength and Conditioning Journal, 39*(2), 34-47. https://doi.org/10.1519/SSC.0000000000000281

Cumming, S.P., Searle, C., Hemsley, J.K., Haswell, F., Edwards, H.J., Scott, S., Gross, A.S., Ryan, D., Lewis, J.A., White, P., Cain, A., Mitchell, S.B., & Malina, R.M. (2018). Biological maturation, relative age and self-regulation in male professional academy soccer players: A test of the underdog hypothesis. *Psychology of Sport and Exercise, 39*(2), 147–153. https://doi.org/10.1016/j.psychsport.2018.08.007

DiFiori, J. P., Benjamin, H. J., Brenner, J. S., Gregory, A., Jayanthi, N., Landry, G. L., & Luke, A. (2014). Overuse injuries and burnout in youth sports: a position statement from the American Medical Society for Sports Medicine. *British journal of sports medicine, 48*(4), 287–288. https://doi.org/10.1136/bjsports-2013-093299

Dorn, L, Dahl, R, Woodward, H & Biro, F. (2006) Defining the boundaries of early adolescence: a user's guide to assessing pubertal status and pubertal timing in research with adolescents. *Applied Developmental Science, 10*(1), 30–56. https://doi.org/10.1207/s1532480zads1001_3

Dupré, T., Lysdal, F. G., Funken, J., Mortensen, K., Müller, R., Mayer, J., Krahl, H., & Potthast, W. (2020). Groin Injuries in Soccer: Investigating the Effect of Age on Adductor Muscle Forces.

Medicine and science in sports and exercise, 52(6), 1330–1337. https://doi.org/10.1249/MSS.0000000000002243

Figueiredo, A. J., Gonçalves, C. E., Coelho E Silva, M. J., & Malina, R. M. (2009). Characteristics of youth soccer players who drop out, persist or move up. *Journal of sports sciences, 27*(9), 883–891. https://doi.org/10.1080/02640410902946469

Fransen, J., Bush, S., Woodcock, S., Novak, A., Deprez, D., Baxter-Jones, A., Vaeyens, R., & Lenoir, M. (2018a). Improving the Prediction of Maturity From Anthropometric Variables Using a Maturity Ratio. *Pediatric exercise science, 30*(2), 296–307. https://doi.org/10.1123/pes.2017-0009

Fransen, J., Baxter-Jones, A., & Woodcock, S. (2018b). Responding to the Commentary on the Article: "Improving the Prediction of Maturity From Anthropometric Variables Using a Maturity Ratio". *Pediatric exercise science, 30*(2), 311–313. https://doi.org/10.1123/pes.2017-0249

Gibbs, B. G., Jarvis, J. A., & Dufur, M. J. (2012). The rise of the underdog? The relative age effect reversal among Canadian-born NHL hockey players: A reply to Nolan and Howell. *International Review for the Sociology of Sport*, *47*(5), 644–649. https://doi.org/10.1177/1012690211414343

Hammami, R., Chaouachi, A., Makhlouf, I., Granacher, U., & Behm, D. G. (2016). Associations Between Balance and Muscle Strength, Power Performance in Male Youth Athletes of Different Maturity Status. *Pediatric exercise science, 28(*4), 521–534. https://doi.org/10.1123/pes.2015-0231

Helsen, W., Winckel, J., & Williams, A. (2005). The relative age effect in youth soccer across Europe. *Journal of sports sciences. 23*(6). 629-636. https://doi.org/10.1080/02640410400021310.

Hill, M., Scott, S., Malina, R. M., McGee, D., & Cumming, S. P. (2020). Relative age and maturation selection biases in academy football. *Journal of sports sciences, 38*(11), 1359–1367. https://doi.org/10.1080/02640414.2019.1649524

Hirose N. (2009). Relationships among birth-month distribution, skeletal age and anthropometric characteristics in adolescent elite soccer players. *Journal of sports sciences, 27*(11), 1159–1166. https://doi.org/10.1080/02640410903225145

Hirose, N & Hirano, A. (2012). The Bias toward Biological Maturation through the Talent Selection in Japanese Elite Youth Soccer Players. *International journal of sports and health science. 10*(3). 30-38. https://doi.org/10.5432/ijshs.201130.

Ingrell, J., Johnson, U. & Ivarsson, A. (2020). Achievement goals in youth sport and the influence of coaches, peers, and parents: A longitudinal study. *Journal of Human Sport and Exercise, 15(*3), 570-590. https://doi.org/10.14198/jhse.2020.153.09

Ingrell, J., Larneby, M., Johnson, U. & Hedenborg, S. (2019). Student-athletes' beliefs about athletic ability *A longitudinal and mixed method gender study, Scandinavian Sport Studies Forum, 10*, 117-138.

Johnson, A., Doherty, P. J., & Freemont, A. (2009). Investigation of growth, development, and factors associated with injury in elite schoolboy footballers: prospective study. *BMJ (Clinical research ed.), 338*. https://doi.org/10.1136/bmj.b490

Johnson, A., Farooq, A. & Whiteley, R. (2017) Skeletal maturation status is more strongly associated with academy selection than birth quarter, *Science and Medicine in Football, 1*(2), 157-163, https://doi.org/10.1080/24733938.2017.1283434

Kemper, H., Verschuur, R. & de Mey L. (1989). Longitudinal changes of aerobic fitness in youth ages 12 to 23. *Pediatric Exercise Science*. 1.257-270. https://doi.org/10.1123/pes.1.3.257

Khamis, H. J., & Roche, A. F. (1994). Predicting adult stature without using skeletal age: the Khamis-Roche method. *Pediatrics, 94*(4 Pt 1), 504–507.

Lesinski, M., Schmelcher, A., Herz, M., Puta, C., Gabriel, H., Arampatzis, A., Laube, G., Büsch, D., & Granacher, U. (2020). Maturation-, age-, and sex-specific anthropometric and physical fitness percentiles of German elite young athletes. *PloS one, 15*(8), e0237423. https://doi.org/10.1371/journal.pone.0237423

Malina, R. M., Baxter-Jones, A. D., Armstrong, N., Beunen, G. P., Caine, D., Daly, R. M., Lewis, R. D., Rogol, A. D., & Russell, K. (2013). Role of intensive training in the growth and maturation of artistic gymnasts. *Sports medicine (Auckland, N.Z.), 43*(9), 783–802. https://doi.org/10.1007/s40279-013-0058-5marsha

Malina, R. M., Claessens, A. L., Van Aken, K., Thomis, M., Lefevre, J., Philippaerts, R., & Beunen, G. P. (2006). Maturity offset in gymnasts: application of a prediction equation. *Medicine and science in sports and exercise, 38*(7), 1342–1347. https://doi.org/10.1249/01.mss.0000227321.61964.09

Malina, R. M., & Kozieł, S. M. (2014). Validation of maturity offset in a longitudinal sample of Polish boys. *Journal of sports sciences, 32*(5), 424–437. https://doi.org/10.1080/02640414.2013.828850

Malina, R. M., Peña Reyes, M. E., Eisenmann, J. C., Horta, L., Rodrigues, J., & Miller, R. (2000). Height, mass and skeletal maturity of elite Portuguese soccer players aged 11-16 years. *Journal of sports sciences, 18*(9), 685–693. https://doi.org/10.1080/02640410050120069

Malina, R. M., Rogol, A. D., Cumming, S., Coelho-e-Silva, M. J., & Figueirido, A. J. (2015). Biological maturation of youth athletes: assessment and implications. *British Journal of Sports Medicine, 49*(13), 852-859. https://doi.org/10.1136/bjsports-2015-094623

Mann, D. L., & van Ginneken, P. J. (2017). Age-ordered shirt numbering reduces the selection bias associated with the relative age effect. *Journal of sports sciences, 35*(8), 784–790. https://doi.org/10.1080/02640414.2016.1189588

Marshall, W. A., & Tanner, J. M. (1970). Variations in the pattern of pubertal changes in boys. *Archives of disease in childhood, 45*(239), 13–23. https://doi.org/10.1136/adc.45.239.13

McGowan, J., Whatman, C., & Walters, S. (2020). The associations of early specialisation and sport volume with musculoskeletal injury in New Zealand children. *Journal of science and medicine in sport, 23*(2), 139–144. https://doi.org/10.1016/j.jsams.2019.09.002

Meylan, C., Cronin, J., Oliver, J., & Hughes, M. (2010). Talent Identification in Soccer: The Role of Maturity Status on Physical, Physiological and Technical Characteristics. *International Journal of Sports Science & Coaching, 5*(4), 571–592. https://doi.org/10.1260/1747-9541.5.4.571

Mirwald, R. L., Baxter-Jones, A. D., Bailey, D. A., & Beunen, G. P. (2002). An assessment of maturity from anthropometric measurements. *Medicine and science in sports and exercise, 34*(4), 689–694. https://doi.org/10.1097/00005768-200204000-00020

Mohr, M., Krustrup, P., & Bangsbo, J. (2003). Match performance of high-standard soccer players with special reference to development of fatigue. *Journal of sports sciences, 21*(7), 519–528. https://doi.org/10.1080/0264041031000071182

Monasterio, X., Gil, S. M., Bidaurrazaga-Letona, I., Lekue, J. A., Santisteban, J., Diaz-Beitia, G., Martin-Garetxana, I., Bikandi, E., & Larruskain, J. (2021). Injuries according to the percentage of adult height in an elite soccer academy. *Journal of science and medicine in sport, 24*(3), 218–223. https://doi.org/10.1016/j.jsams.2020.08.004

Myburgh, G. K., Cumming, S. P., Coelho E Silva, M., Cooke, K., & Malina, R. M. (2016). Growth and maturity status of elite British junior tennis players. *Journal of sports sciences, 34*(20), 1957–1964. https://doi.org/10.1080/02640414.2016.1149213

Ostojic, S. M., Castagna, C., Calleja-González, J., Jukic, I., Idrizovic, K., & Stojanovic, M. (2014). The biological age of 14-year-old boys and success in adult soccer: do early maturers predominate in the top-level game?. *Research in sports medicine, 22*(4), 398–407. https://doi.org/10.1080/15438627.2014.944303

Papadopoulou, S. D., Papadopoulou, S. K., Rosemann, T., Knechtle, B., & Nikolaidis, P. T. (2019). Relative Age Effect on Youth Female Volleyball Players: A Pilot Study on Its Prevalence and Relationship With Anthropometric and Physiological Characteristics. *Frontiers in psychology, 10*, 2737. https://doi.org/10.3389/fpsyg.2019.02737

Parr, J., Winwood, K., Hodson-Tole, E., Deconinck, F., Parry, L., Hill, J. P., Malina, R. M., & Cumming, S. P. (2020). Predicting the timing of the peak of the pubertal growth spurt in elite male youth soccer players: evaluation of methods. *Annals of human biology, 47*(4), 400–408. https://doi.org/10.1080/03014460.2020.1782989

ParticipACTION. (2018). *The Brain + Body Equation: Canadian kids need active bodies to build their best brains. The 2018 ParticipACTION Report Card on Physical Activity for Children and Youth*. https://participaction.cdn.prismic.io/participaction%2F38570bed-b325-4fc8-8855-f15c9aebac12_2018_participaction_report_card_-_full_report_0.pdf

Patel, R., Nevill, A., Cloak, R., Smith, T., & Wyon, M. (2019). Relative age, maturation, anthropometry and physical performance characteristics of players within an Elite Youth Football Academy. *International Journal of Sports Science & Coaching, 14*(3). https://doi.org/10.1177/1747954119879348.

Philippaerts, R. M., Vaeyens, R., Janssens, M., Van Renterghem, B., Matthys, D., Craen, R., Bourgois, J., Vrijens, J., Beunen, G., & Malina, R. M. (2006). The relationship between peak height velocity and physical performance in youth soccer players. *Journal of sports sciences, 24(*3), 221–230. https://doi.org/10.1080/02640410500189371

Read, P. J., Oliver, J. L., De Ste Croix, M. B., Myer, G. D., & Lloyd, R. S. (2016). The scientific foundations and associated injury risks of early soccer specialisation. *Journal of sports sciences, 34*(24), 2295–2302. https://doi.org/10.1080/02640414.2016.1173221

Read, P. J., Oliver, J. L., De Ste Croix, M., Myer, G. D., & Lloyd, R. S. (2018). An audit of injuries in six english professional soccer academies. *Journal of sports sciences, 36*(13), 1542–1548. https://doi.org/10.1080/02640414.2017.1402535

Reilly, T., Williams, A., Nevill, A., & Franks, A. (2000). A multidisciplinary approach to talent identification in soccer. *Journal of Sports Sciences, 18*(9), 695–702. DOI: https://doi.org/10.1080/02640410050120078

Ritzer, E. E., Yang, J., Kistamgari, S., Collins, C. L., & Smith, G. A. (2021). An epidemiologic comparison of acute and overuse injuries in high school sports. *Injury epidemiology, 8*(1), 51. https://doi.org/10.1186/s40621-021-00344-8

Roche, A.F., Chumlea, W.C. and Thissen, D., (1988), Assessing the Skeletal Maturity of the Hand-Wrist: Fels Method. (Springfield: Charles C. Thomas). Or Chumela, W. C., Roche, A. F., & Thissen, D. (1989). The FELS method of assessing the skeletal maturity of the hand-wrist. *American journal of human biology : the official journal of the Human Biology Council, 1*(2), 175–183. https://doi.org/10.1002/ajhb.1310010206

Roemmich, J. N., & Rogol, A. D. (1995). Physiology of growth and development. Its relationship to performance in the young athlete. *Clinics in sports medicine, 14*(3), 483–502.

Salter J, Cumming S, Hughes JD, De Ste Croix M. (2022). Estimating somatic maturity in adolescent soccer players: Methodological comparisons. I*nternational Journal of Sports Science & Coaching. 17*(1):11-17. https://doi.org/10.1177/17479541211020418

Salter, J., De Ste Croix, M., Hughes, J. D., Weston, M., & Towlson, C. (2021). Monitoring Practices of Training Load and Biological Maturity in UK Soccer academies. *International journal of sports physiology and performance, 16*(3), 395–406. https://doi.org/10.1123/ijspp.2019-0624

Sanders, J. O., Qiu, X., Lu, X., Duren, D. L., Liu, R. W., Dang, D., Menendez, M. E., Hans, S. D., Weber, D. R., & Cooperman, D. R. (2017). The Uniform Pattern of Growth and Skeletal Maturation during the Human Adolescent Growth Spurt. *Scientific reports, 7*(1), 16705. https://doi.org/10.1038/s41598-017-16996-w

Sherar, L. B., Baxter-Jones, A. D., Faulkner, R. A., & Russell, K. W. (2007). Do physical maturity and birth date predict talent in male youth ice hockey players?. *Journal of sports sciences, 25*(8), 879–886. https://doi.org/10.1080/02640410600908001

Sport England. (2021). *Active Lives Children and Young People Survey Academic year 2019/20* https://sportengland-production-files.s3.eu-west-2.amazonaws.com/s3fs-public/2021-01/Active%20Lives%20Children%20Survey%20Academic%20Year%2019-20%20report.pdf?VersionId=4Ti_0V0m9sYy5HwQjSiJN7Xj.VInpjV6

Sport New Zealand. (2019). *Active NZ 2018 Participation Report.* Sport New Zealand. https://sportnz.org.nz/media/1440/published-final-active-nz-main-report-the-new-zealand-participation-survey-2018-12-august-2019.pdf

Toum, M., Tribolet, R., Watsford, M. L., & Fransen, J. (2020). The confounding effect of biological maturity on talent identification and selection within youth Australian football. *Science & medicine in football, 5*(4), 263–271. https://doi.org/10.1080/24733938.2020.1822540

Tribolet, R., Bennett, K., Watsford, M. L., & Fransen, J. (2018). A multidimensional approach to talent identification and selection in high-level youth Australian Football players. *Journal of sports sciences, 36*(22), 2537–2543. https://doi.org/10.1080/02640414.2018.1468301

U.S. Department of Health and Human Services. (2019). *The National Youth Sports Strategy*. U.S. Department of Health and Human Services. https://health.gov/sites/default/files/2019-10/National_Youth_Sports_Strategy.pdf

Vaeyens, R., Lenoir, M., Williams, A. M., Mazyn, L., & Philippaerts, R. M. (2007). The effects of task constraints on visual search behavior and decision-making skill in youth soccer players. *Journal of sport & exercise psychology, 29*(2), 147–169. https://doi.org/10.1123/jsep.29.2.147

Vaeyens, R., Lenoir, M., Williams, A. M., & Philippaerts, R. M. (2008). Talent identification and development programmes in sport: current models and future directions. *Sports medicine (Auckland, N.Z.), 38*(9), 703–714. https://doi.org/10.2165/00007256-200838090-00001

Vaeyens, R., Philippaerts, R., & Malina, R. (2005). The relative age effect in soccer: A match-related perspective. *Journal of sports sciences*. *23*(7). 747-56. https://doi.org/10.1080/02640410400022052.

van der Sluis, A., Elferink-Gemser, M. T., Coelho-e-Silva, M. J., Nijboer, J. A., Brink, M. S., & Visscher, C. (2014). Sport injuries aligned to peak height velocity in talented pubertal soccer players. *International journal of sports medicine, 35*(4), 351–355. https://doi.org/10.1055/s-0033-1349874

Van Hooren, B., & De Ste Croix, M. (2020). Sensitive Periods to Train General Motor Abilities in Children and Adolescents: Do They Exist? A Critical Appraisal. *Strength and Conditioning Journal, (42*(6). 7-14. https://doi.org/10.1519/SSC.0000000000000545

Verbeek, Jan & Lawrence, Steve & Breggen, Jorg & Kelly, Adam & Jonker, Laura. (2021). The average team age method and its potential to reduce relative age effects. *Birth Advantages and Relative Age Effects in Sport, 1*(1), 107-124. https://doi.org/10.4324/9781003163572-10.

Visek, A. J., Achrati, S. M., Mannix, H., McDonnell, K., Harris, B. S., & DiPietro, L. (2015). The fun integration theory: toward sustaining children and adolescents sport participation. *Journal of physical activity & health, 12*(3), 424–433. https://doi.org/10.1123/jpah.2013-0180

Ward, P., & Williams, A. (2003). Perceptual and Cognitive Skill Development in Soccer: The Multidimentional Nature of Expert Performance. *Journal of Sport and Exercise Psychology, 25(*1), 93-111. https://doi.org/10.1123/jsep.25.1.93

Wilder, R. P., & Sethi, S. (2004). Overuse injuries: tendinopathies, stress fractures, compartment syndrome, and shin splints. *Clinics in sports medicine, 23*(1), 55–81. https://doi.org/10.1016/S0278-5919(03)00085-1

Williams, A. M., & Reilly, T. (2000). Talent identification and development in soccer. *Journal of sports sciences, 18*(9), 657–667. https://doi.org/10.1080/02640410050120041

Yoshiga, C. C., & Higuchi, M. (2003). Rowing performance of female and male rowers. *Scandinavian journal of medicine & science in sports, 13*(5), 317–321. https://doi.org/10.1034/j.1600-0838.2003.00321.x

Zwiren L. D. (1989). Anaerobic and aerobic capacities of children. *Pediatric Exercise Science, 1*(1), 31-44. https://doi.org/10.1123/pes.1.1.31

Appendices

Appendix A: Ethics Approval

Auckland University of Technology Ethics Committee (AUTEC)

TE WĀNANGA ARONUI O TĀMAKI MAKAU RAU

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

12 April 2022

Chris Whatman
Faculty of Health and Environmental Sciences

Dear Chris

Re Ethics Application: **22/47 Links between the adolescent growth spurt, team selection and injury history in secondary school sports teams**

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 8 April 2025.

Non-Standard Conditions of Approval

1. Please ensure that it is the researcher (not the employees) that seeks the permission from the principal for access to school.
2. You are advised that you will be holding contact details of participants as they will submitting a Consent Form with these details.
3. On the parent Consent Form and Child Assent Form you still need to include a yes/no option to receive individual results.
4. The phrase 'drop out is still in the student Information Sheet.

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

Standard Conditions of Approval

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

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

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

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

The AUTEC Secretariat
Auckland University of Technology Ethics Committee

Cc: Tomcooper099@gmail.com

Appendix B: Parent and Player Information Sheets

AUT
TE WĀNANGA ARONUI
O TĀMAKI MAKAU RAU

Parent Information Sheet

Date Information Sheet Produced:

29-03-2022

Project Title

Biological growth and injury history in secondary schools sports teams

An Invitation

Dear Parent/Legal Guardian,

Westlake Boys High School has teamed up with an AUT University Masters student to conduct a study investigating the relationship between maturation (growing up) and performance. This study will take place alongside the Westlake Boys sport team training programme that your child is taking part in.

Please read this information sheet carefully before deciding if you would like your child to take part or not. If you do decide for your child to participate, we thank you. If you decide for your child not to take part, there will be no disadvantage to you or your child of any kind and we thank you for thinking about it. Note we will also need assent from your child for them to be able to participate.

If you do agree for your child to take part, we are also asking for the height of both biological parents of your child.

What is the purpose of this research?

The aim of this project is to better understand physical maturation (getting bigger and stronger), improve team selections and reduce injury in players aged 12-15 years. It is hoped the findings will lead to a fairer method of selection and reduce injury risk in this age group. This will mean a safer and more positive experience for more children who play sport. The data collected may be used to guide how schools choose players for teams and assist with injury prevention strategies.

The findings of this research may be used for academic publications and presentations.

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

Your child and their team mates were identified and can take part because they are playing in a Westlake Boys junior sports team (football, rugby, hockey, basketball, cricket, rowing). We also require some information from you, as the parent.

How do I agree to participate in this research?

If you are happy for your child to take part, please fill out the consent form accompanying this information sheet. Please return the consent form to the research team on the day of data collection (date to be advised when these information and consent sheets are distributed). Your child's participation in this research is voluntary and whether or not you and your child choose to participate will neither advantage nor disadvantage you or your child. Your child is able to withdraw from the study at any time. If your child chooses to withdraw from the study, then you/your child will be offered the choice between having any data that is identifiable as belonging to your child removed or allowing it to continue to be used. However, once the findings have been produced, removal of your child's data may not be possible.

What will happen in this research?

1. Growth measurements, including standing, seated height and weight will be taken at the start of one of your child's sport training sessions. They will also be asked to fill out a short survey about their injury history.
2. We would also like you to provide your height (both biological parents). Along with your child's growth measures, Parent height allows us to estimate the maturational status of your child. Please measure your own heights following the instructions provided on the attached data information sheet then return it with the relevant consent. If you do not wish to share this, or are not the biological parents of your child, leave this section blank.

The maturity estimation that will be used in the study requires biological parent height. The purpose for choosing this method is that is the most widely applied method of maturity estimation in youth team sports worldwide. This method allows for an accurate estimation of current stage of biological growth for the participant in relation to parental height.

What are the discomforts and risks?

There are no anticipated risks to taking part in the study and your child should not experience any discomfort.

What are the benefits?

This study has the potential to improve the way that teams are selected, giving more players a better chance of team participation. This is likely to reduce premature dropout from sport, injury and burnout and enhance the wellbeing benefits that can be accrued from positive sporting experiences.

A further benefit will be that the primary researcher will be obtaining a degree

How will my privacy be protected?

The measurements will be collected by the primary researcher (AUT Masters student) and stored and analysed by the primary researcher (contact details below). The data will be held on a secure database which will only be accessed by the research team. Coaches will not have access to any individual player data.

What are the costs of participating in this research?

There will be no monetary cost to you or your child to be involved in this research, the only cost is time. We anticipate that it will take 10 minutes. The data will be collected within school hours during the participant's sports class.

What opportunity do I have to consider this invitation?

You have two weeks to consider this invitation.

Will I receive feedback on the results of this research?

Yes, AUT will provide the school with a summary of the findings from the research. You can also have access to your child's individual results if you choose. If you wish to receive your child's results please circle YES in the Consent form below. A report will be sent to you at the completion of the study

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 primary supervisor, Dr Chris Whatman, chris.whatman@aut.ac.nz, 021 1869922

Concerns regarding the conduct of the research should be notified to the Executive Secretary of AUTEC, *ethics@aut.ac.nz*, (+9) 921 9999 ext 6038.

Whom do I contact for further information about this research?

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

Researcher Contact Details:

Mr Tom Cooper, *tomcooper099@gmail.com, 021 1814804*

Project Supervisor Contact Details:

Dr Chris Whatman, Supervisor, chris.whatman@aut.ac.nz, 021 1869922

Player U16 Information Sheet

Date Information Sheet Produced:

29-03-2022

Project Title

Biological growth and injury history in secondary schools sports teams

An Invitation

Dear Player,

Westlake Boys High School has teamed with researchers at AUT University to conduct a study investigating the relationship between growing up, injury and selection into sports teams. This will take place alongside the school sports trainings you are taking part in.

Please read this information sheet carefully before deciding if you would like to take part or not. If you do decide to participate, we thank you. If you decide not to take part, there will be no disadvantage to you of any kind and we thank you for thinking about it.

What is the purpose of this research?

The aim of this project is to better understand physical growth (getting bigger and stronger) and injury in players aged 12-15 in our country. It is hoped the findings will lead to an improved method of training and selecting teams and help reduce injuries. This will mean safer and more enjoyable sport for more youth. The data collected will be used to guide how we run our training programmes and choose players for teams in the future.

The findings of this research may be used for university publications and presentations.

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

You and your team mates were identified and can take part because you play in a team sport (football, rugby, hockey, basketball, cricket, rowing) at Westlake Boys High School.

How do I agree to participate in this research?

If you are happy to take part, please fill out the assent (permission) form accompanying this information sheet and ask your parents to fill in a parental consent form. Please return both the consent (parental) and assent (player) form to the research team on the day of data collection (date to be advised when these information and assent sheets are distributed). Your participation in this research is your choice and whether or not you choose to participate will neither advantage nor disadvantage you. You are able to withdraw of the study at any time. If you choose to withdraw of the study, then you will be offered the choice between having any data that is identifiable as belonging to you removed or allowing it to continue to be used. However, once the findings have been produced, removal of your data may not be possible.

What will happen in this research?

1. Growth measurements, including standing height, seated height and weight will be taken at the start of one of your sport training sessions.

2. We will need you to ask your parents to provide their height as well. They can measure their own heights following the instructions provided on an additional data information sheet you will be provided.

   The maturity estimation that will be used in the study requires biological parent height. The purpose for choosing this method is that is the most widely applied method of maturity estimation in youth team sports worldwide. This method allows for an accurate estimation of current stage of biological growth for the participant in relation to parental height.

3. You will also need to complete a short survey about any past injuries playing sport.

What are the discomforts and risks?

There are no anticipated risks to taking part and you should not experience any discomfort.

Taking part (or not) in the study will not affect you chances of being selected for teams.

What are the benefits?

This study has the potential to improve the way teams are selected, giving more players a better chance of positive sport participation. This is likely to reduce early dropout from sport, injury and burnout and enhance the school sport experience. It will also help make sport safer.

A further benefit will be that the primary researcher will be obtaining a degree

How will my privacy be protected?

The measurements will be collected by the primary researcher (AUT Masters student) and stored and analysed by the primary researcher (contact details below). The data will be held on a secure database which will only be accessed by the research team. Coaches will not have access to any individual player data.

What are the costs of participating in this research?

There will be no monetary cost to you to be involved in this research, the only cost is time. We anticipate that it will take 10 minutes. The data will be collected within school hours during the participant's sports class.

What opportunity do I have to consider this invitation?

You have two weeks to consider this invitation.

Will I receive feedback on the results of this research?

Yes, AUT will provide you with findings from the research. You can also have access to your individual results if you choose. If you wish to receive your individual results, please circle YES in the Assent form below. A report will be sent to you at the completion of the study

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 primary supervisor, Dr Chris Whatman, chris.whatman@aut.ac.nz, 021 1869922

Concerns regarding the conduct of the research should be notified to the Executive Secretary of AUTEC, *ethics@aut.ac.nz*, (+9) 921 9999 ext 6038.

Whom do I contact for further information about this research?

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

Researcher Contact Details:

Mr Tom Cooper, *tomcooper099@gmail.com, 021 1814804*

Project Supervisor Contact Details:

Dr Chris Whatman, Supervisor, chris.whatman@aut.ac.nz, 021 1869922

If you would like to participate in the project, please complete the consent form on the next page.

Thank you for considering taking part in the Westlake Boys Maturation project.

Approved by the Auckland University of Technology Ethics Committee on 12-04-2022, AUTEC Reference number *22/47*

Appendix C: Parent Consent and Player Assent Forms

TE WĀNANGA ARONUI O TĀMAKI MAKAU RAU

Parent Consent Form

Project title: ***Maturation Status and Injury history in Secondary School sports teams***

Project Supervisor: ***Dr Chris Whatman, chris.whatman@aut.ac.nz, 021 1869922***

Researcher: ***Tom Cooper, tomcooper099@gmail.com, 021 1814804***

- ○ I have read and understood the information provided about this research project in the Information Sheet dated 29/03/22
- ○ I have had an opportunity to ask questions and to have them answered.
- ○ I understand that taking part in this study is voluntary and that my child may withdraw from the study at any time without being disadvantaged in any way.
- ○ I understand that if my child withdraws from the study then they will be offered the choice between having any data that is identifiable as belonging to them removed or allowing it to continue to be used. However, once the findings have been produced, removal of their data may not be possible.
- ○ I agree to my child taking part in this research.
- ○ I agree to be measured
- ○ I wish to receive a summary of the research findings (please circle):

  Yes No

- ○ I wish to receive my child's individual results (please circle):

  Yes No

Player name: ……………………………………………………………………

Parent/Guardian Signature: ……………………………………………………………………

I agree to my child taking part in this project.

Date: ……………………………………

Note: Please return this form to Tom Cooper – tomcooper099@gmail.com, 021 1814804

Approved by the Auckland University of Technology Ethics Committee on 12-04-2022, AUTEC Reference number 22/47

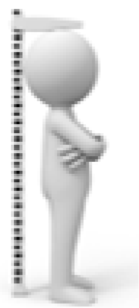
Data information sheet – Parent's Height

Project title: ***Maturation Status and Injury History in Secondary School sports teams***

Project Supervisor: ***Dr Chris Whatman, chris.whatman@aut.ac.nz, 021 1869922***

Researcher: ***Tom Cooper, tomcooper099@gmail.com, 021 1814804***

1. Find someone to help – they will be taking the measurement.
2. Remove your shoes, bulky clothing, and hair ornaments, and unbraid hair that interferes with the measurement.
3. Take the height measurement on flooring that is not carpeted and against a flat surface such as a wall.
4. Stand with feet flat, together, and against the wall. Make sure your legs are straight, arms are at your side, and shoulders are level.
5. Look straight ahead with your line of sight parallel with the floor.
6. Have you helper take the measurement while you stand with head, shoulders, buttocks, and heels touching the flat surface (wall).
7. Use a flat headpiece (e.g., a hard cover book) to form a right angle with the wall and lower the headpiece until it firmly touches the crown of the head.
8. Make sure the measurer's eyes are at the same level as the headpiece.
9. Lightly mark where the bottom of the headpiece meets the wall. Then, use a metal tape to measure from the base of the floor to the marked measurement on the wall to get the height measurement.
10. Accurately record the height to the nearest 0.1 centimeter.



Mother's height: ………………………………………………………………….

Father's height: …………………………………………………………………..

Parent/Guardian Signature:

I agree to this information being using in this project.

Parent/Guardian Email:……………………………………………………

Note: Please return this form to Tom Cooper – tomcooper099@gmail.com, 021 1814804

Approved by the Auckland University of Technology Ethics Committee on 12-04-2022, AUTEC Reference number 22/47

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

AUT
TE WĀNANGA ARONUI O TĀMAKI MAKAU RAU

Player U16 Assent Form

Project title: ***Maturation (growth) status and Injury history in Secondary School sports teams***

Project Supervisor: ***Dr Chris Whatman, chris.whatman@aut.ac.nz, +64 21 1869922***

Researcher: ***Tom Cooper, tomcooper099@gmail.com, +64 21 1814804***

○ I have read and understood the information provided about this research project in the Information Sheet dated 29th March 2022

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

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

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

○ I agree to take part in this research.

○ I agree to be measured

○ I wish to receive a summary of the research findings (please circle):

Yes No

○ I wish to receive my child's individual results (please circle):

Yes No

Participant's signature: ....

Participant's name: ....

Date:

Parent/Guardian Email:..

Note: Please return this form to Tom Cooper – tomcooper099@gmail.com, +64 21 1814804

Approved by the Auckland University of Technology Ethics Committee on 12-04-2022, AUTEC Reference number 22/47

This questionnaire asks you to report on injuries you have sustained playing organised sport in the past 3 months. Please read the instructions 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.***

Sport Injury Questionnaire

Demographic Questions

1 Are you?

- Male
- Female

2 Birth Year and Birth Month

3 Sports Team

4 Ethnicity

Injury history

The following section asks about injuries that you have had from playing or training during your organised sport over the **past 3 months**

5 Have you experienced any injuries playing or practicing organised sport that caused you to miss any practice, game or competition?

- Yes → Go to 6
- No → Go to 7

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

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

- Yes → Mark on chart as in Q6.
- No → Thank-you for completing the survey.

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

For research assistant use only