The Athletic Development of Junior Tennis Players

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A thesis submitted to Auckland University of Technology in fulfilment of the requirements of the degree of Doctor of Philosophy (PhD)

July 2021

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Abstract

Paediatric strength and conditioning (S&C) research has gained significant momentum in recent years, as evidence has continually highlighted the physiological differences between youth and adult athletes, and the subsequent need for different approaches to athletic development. Substantial evidence exists demonstrating the benefits of formal S&C programmes on fitness, motor skill performance and general health and wellbeing of youth athletes. Despite this, limited information specifically relating this to tennis performance means that often technical, tactical and skill development remains the key focus during early training years.

Synthesis of the two literature reviews highlighted a gap in empirical data relating to U14 and female players. Therefore, one of the overarching aims of this thesis was to gain understanding on how formal strength and conditioning influences athletic development of players aged 10-14 years old of both genders and subsequently how this influences tennis performance.

The first part of this thesis sought to identify current trends in the physical fitness and training characteristics of the New Zealand population, with a view to enabling comparison to international peers and facilitate better understanding of the training requirements of young players. Study 1 identified that key physical attributes and trends which influence tennis performance did not differ greatly from those observed in the cohorts of previous studies. The findings indicated that upper body power and strength should be a priority focus of tennis players fitness programmes in this age group. Study 2 also drew attention to a notably lower training volumes of NZ players particularly regarding physical S&C training. This identified a possible weakness in the current practice of players and/or coaches in this country. The significance of how these lower volumes impact on players achieving their physical potential or ultimately the progression of their tennis careers is not clearly understood. Study 3 provided the first indication that those following a structured formal S&C programme over several years had better performance outcomes than those who did not. This information provided justification and support for the introduction of S&C at an early age for those not already participating in formal physical training.

The development of fundamental movement skills (FMS) during childhood and adolescence has been identified as a priority training focus (Lloyd and Oliver, 2012). As previous research has not evaluated how FMS competency influences physical fitness or tennis performance, the second part of this thesis focused on the practical application of FMS assessment and training protocols. The findings from Study 4 indicated the assessment of FMS via Athletic Ability assessment (AAA) movement screening may be a valuable tool for S&C coaches with junior tennis players.

Significant relationships between screening scores and performance indicated that data gathered may provide insight into strengths and weaknesses of an individual's movement competency, which can help guide exercise prescription to enhance performance. In turn, the introduction of simple 6-week FMS and strength training interventions to this population was shown to have positive influence on both the movement competency and physical fitness performance of players in this age group. Although there was no acute transfer to tennis performance, given the correlations shown in the first half of thesis it may be fair to assume that making improvements in these areas will eventually have a carryover effect on an individual's ability to play tennis.

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Attestation of authorship

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

Emily Carter

July 2021

Co-authored works

The physical fitness, growth and anthropometric characteristics of New Zealand Junior Tennis players and their relationship to Tennis performance.

To be submitted to the *Journal of Strength and Conditioning Research* (Emily Carter 90%, Michael McGuigan 5%, Andrew Kilding 5%)

The impact of a 6-week FMS training intervention on the movement competency, physical fitness and tennis performance of junior tennis players aged 10-15 years old.

To be submitted to the *Journal of Strength and Conditioning Research* (Emily Carter 90%, Michael McGuigan 5%, Andrew Kilding 5%)

Emily Carter

Michael McGuigan

Andrew E Kilding

Acknowledgements

Since I was very young, I knew I wanted to be a doctor. Admittedly, it was of the medical kind for the first 10 years of that dream, before getting a bit worried as a teenager applying for university, I might be a bit too emotional to cope with not being able to save everybody and opting for the softer option of physiotherapy for my undergraduate degree! Nevertheless, it was still a title I wanted to achieve and post master's degree, my passion for continual learning and self-development led me down the path of looking for the right topic and place to complete a Doctorate in Philosophy. Having accidentally fallen into working in junior tennis in 2010 and simultaneously fallen in love with the sport, when a PhD Scholarship with AUT and role with Tennis NZ was passed my way in 2014, it seemed too good to be true! The journey since that day has not been plain sailing in any way and I could not have completed this thesis without the help of many people who I have guided, advised, loved and supported me all this time.

Firstly, to my supervisors Mike McGuigan and Andy Kilding you both have been eternally patient and positive. Mike your cool, calm and relaxed approach has always helped settle my anxiety when I have struggled with balancing a full-on job and completing this thesis, then later juggling motherhood into the mix too. Your prompt feedback and expert guidance has been invaluable and provided me the feeling of being supported throughout the process, and I cannot thank you enough. Andy, you have always greeted me with a cheerful and optimistic attitude that has boosted my belief in my ability to complete this PhD. I am lucky to have had an academic of your calibre, with your knowledge and experience behind me, providing the clear and concise that I needed when feeling lost! So, a huge thank you to both of you, for everything you have done!

Secondly, to my husband Nathan, the last 6.5 years has been a wild ride. We have gone through many high and lows since moving here from London, and you have been there to support me throughout it all, which has not been easy! We have survived the lows of a life-threatening illness and a long recovery journey for you, weeks and months apart with my travel for Tennis NZ and working 60-hrs weeks and a global pandemic, involving a lot of homesickness and missed loved ones. But we have also thrived in this beautiful country, had many adventures, organised a wedding full of international guests and brought our beautiful boy, Arlo Beau into this world and are 2-weeks away from meeting our darling little girl! Our family means everything to me, and I hope in completing this I can make them proud.

To all the people at AUT SPRINZ and Tennis New Zealand; Lee Bridgeman, Simon Rea, Christophe Lambert, Matt Alexander, Jessica Bush, Julia Casadio, Anushka Bhrgrava, Tom Stewart, Enora Le Flao, Jane Hall (and many more not listed!), you have gone out of your way to support me,

whether it has been giving advice, helping with data collection, proof reading, marking screenings, being assistant coaches during the intervention studies, the list goes on, but I will be eternally grateful for all your help and could not have done it without you.

To my parents, allowing me to move across the world to pursue my academic dreams and instilling in me values that have enabled me to get to where I am today, thank you. Your unwavering love and support are something I never take for granted and hope I can be half as good a role model for my children that you have been for me. Your belief in me and wanting to make you proud has played in a huge part in getting this across the line, and I feel so blessed to have you as parents.

Lastly, to my vast support network of family and friends in NZ, UK and around the world, thank you for all your understanding, support, encouragement, and patience throughout this tiresome nearly 7-year journey. I know I have not had the time to I would have liked to keep in touch/spend time with you that I wanted, but love you all and think about you lots, and I am looking forward to the freedom I will have when not trying to do two full time jobs, so we can make more memories together. Special thanks to my siblings Andrew and Rebecca, always loving me no matter what. To NZ friends (some who no longer live here) you have all made living here so much fun and introduced me to so many new adventures and activities. I am excited to go on new adventures now all my spare time is not spent studying!

Ethics approval

Ethics approval to conduct this research was granted by the Auckland University of Technology Ethics Committee (AUTEC):

> **The effects of strength and conditioning on the physical performance of junior tennis players, 16/131, 15 May 2016.**

Chapter 1 – Introduction

1.1 Thesis rationale

In the last 25 years there has been substantial research on strength and conditioning (S&C) for youth and adolescent athletes (Faigenbaum and Myer, 2010, Myer et al., 2013, Lloyd and Oliver, 2012). A major focus of this work has been to clarify the safety and efficacy of allowing this population to participate in resistance training. This has been in order to overcome previous misconceptions of injury risk and growth-related issues associated with this form of training (Lloyd et al., 2014, Faigenbaum, 2000, Myer et al., 2013).

Studies showing positive improvements in multiple areas of health and fitness, allows professional and academic associations to advocate the use of a number of different types of training within paediatric populations, including resistance, plyometric and endurance programmes (Oliver et al., 2011, Oliver et al., 2013, Lloyd et al., 2012b, Lloyd et al., 2011a, Faigenbaum et al., 2007, Faigenbaum and Myer, 2010). However, there is only a limited number of studies that have looked at the impact these training interventions have on the development and performance of youth tennis players. Regression analysis of junior ITF (International Tennis Federation) ranking shows a rising probability of achieving a professional ranking with increasing junior success, with 70% likelihood of players reaching a top-100 and 90% for those achieving top-20 (Reid et al., 2007b, Reid et al., 2009a). In an attempt to attain these benchmarks as early as possible, it is common for junior tennis players and coaches to be overly outcome focused during the developmental years, with high competition to training ratios (Kovacs, 2016). As players are eligible to play ITF tournaments from the age of 13, optimising physical training prior to this time, may be of key importance in creating resilience in young players' ability to cope with the physical demands of heavy tournament schedules and competing against players up to 5 years older. The timing of this may vary on an individual basis, but for most players this preparatory period is generally between the ages of 11 and 14/15 years old during the stages preadolescence and early adolescence the "training to train" stage (Balyi and Hamilton, 2003). It has been suggested that lack of knowledge regarding planning and conditions of players development, has led to overtraining, inappropriate training and early specialisation causing early burn out, drop out and retirement of a large number of talented players (Balyi and Hamilton, 2003, Unierzyski et al., 2003). Further research is therefore required to inform this process to both enhance the chances of young players maximising their potential and reduce the risk of the negative impacts identified above from occurring.

Multiple components of fitness are correlated to tennis performance, meaning the development of good all-around athletic ability is necessary to achieve success (Kovacs, 2009, Fernandez-

Fernandez et al., 2008). Skill is a prerequisite, but game style and tactical skill amongst other factors, will allow some athletes to optimise their individual capabilities. This means they can use their strengths to their advantage whilst sometimes masking or avoiding their weaknesses. Subsequently the key component of fitness may be different for each player (Reid et al., 2003, Roetert et al., 1992). In terms of sport performance, it is well established that children lacking movement proficiency often struggle to confidently participate in sport due to an inability to cope with the complex physical demands (Ford et al., 2011). It has also been suggested that youth athlete sport performance is limited by a "proficiency barrier", where the acquisition and execution of more advanced sport-specific skills is limited by the prior foundation of fundamental movement skills (Gallahue and Donnelly, 2007).

In recent years, the development of functional movement and corrective exercise screens to measure proficiency in fundamental tasks have provided a method of assessment for S&C coaches that can be completed quickly and with minimal equipment (Lloyd et al., 2015, McKeown et al., 2014, Cook, 2010). The information from these assessments aims to provide insight into an athlete's level of physical competency and readiness to train, furthermore enabling the coach to prescribe exercise and complexity appropriately (Bodden et al., 2015, Wright et al., 2015). At elite levels, pre-participation medical screenings are used to check for the presence of common tennis-induced musculoskeletal and postural maladaptation's, as previous research has shown a strong link between these changes and injury (Ochi and Campbell, 2009, Reid et al., 2003, Ellenbecker et al., 2009, Abrams et al., 2012, Kibler and Safran, 2005). Anecdotally, functional movement screens may be widely used, despite the lack of peer reviewed research with respect to their efficacy as an assessment tool in tennis players. Furthermore, the lack of movement proficiency as determined by functional movement screens had yet to be linked with performance or injury risk when commencing this thesis and only one author has investigated these relationships since focusing on under 10 years of age (U10) players (Yildiz, 2018, Yildiz et al., 2019). Previous research has highlighted the increased susceptibility to injury of youth immediately prior and during peak height velocity (PHV) (Van Der Sluis et al., 2014, Hjelm et al., 2012).Studies have also demonstrated increased risk of injuries in those with under developed athletic movement competencies and fundamental movement skills (Sommerfield et al., 2021).Therefore in the interest of the safety, assessment of movement competency prior to exercise prescription has some justification. Gaining an empirical understanding of the relationship or lack thereof, between movement quality and tennis performance and the prevention of sport-acquired injury can only enhance the athletic development of young tennis players and improve interpretation of screening results

There is a large body of evidence highlighting the benefits of structured athlete development programmes on fitness, motor skill performance and general health and wellbeing of youth athletes (Faigenbaum et al., 1999, Faigenbaum et al., 2007, Wright et al., 2015, Logan et al., 2012). Despite this evidence, limited literature specifically relating this to tennis performance means often technical, tactical and skill development remains the key focus during early training years (Kovacs, 2016). However, a great deal of research regarding the most effective and efficient way to plan and programme to maximise the long-term physical development of young athletes has been undertaken. Comprehensive LTAD (Long Term Athlete Development) models have been developed in an attempt to cater for this multi factorial process and provide guidelines for S&C coaches working with young players (Balyi and Hamilton, 2003, Cobley et al., 2014, Ford et al., 2011, Lloyd and Oliver, 2012, McKeown and Ball, 2013). Current recommendations in tennis literature regarding the development of junior players generally align with these models (Reid et al., 2003, Kovacs, 2016). However, some of the unique idiosyncrasies of tennis discussed later in this thesis, in particular the influence of junior success on professional career pathways makes following these guidelines prescribed in LTAD models less straightforward than in other sports. The current talent development pathway in NZ does not involve objective consideration of athletic potential. Instead, it is dependent on the players meeting national and international ranking benchmarks relevant to their birth year after the age of 12, in addition to participation and results in competition (Accessed at www.tennis.kiwi).

1.2 Purpose of Research

The overarching aims of this thesis was to investigate the influence structured S&C has on the athletic development of youth tennis players between the age of 10-15 years old. In order to understand this, the thesis sought to understand the relationships between a player’s starting level of movement competency and markers of performance. In addition, how this may be influenced by previous training experience, current training schedule and could be impacted through different types of training was also investigated.

The specific objectives of this thesis were:

1. Investigate the relationships between physical ability, maturation and tennis performance in youth tennis players in New Zealand (NZ).
2. Document the current training characteristics of NZ U14 players with a view to comparing these with existing recommendations and international peers.
3. Explore the individual longitudinal physical development trajectories of youth tennis players from different training backgrounds from the age of 11-15.

4. Investigate the efficacy of using a modified version of the Athletic Ability Assessment movement screen as an assessment tool in junior tennis and quantify the nature of the relationship between screening scores and performance.
5. Investigate the impact a 6-week fundamental movement skills (FMS) training block on markers of tennis performance, physical fitness and movement competency.
6. Investigate the impact of a 6-week strength training block on markers of tennis performance, physical fitness and movement competency.

1.3 Significance of the thesis

Long term athletic development requires continual monitoring and frequent assessment to guide optimal intervention into the training programmes of young athletes, as they experience the physiological changes of growth and maturation at highly individual rates and timings (Lloyd and Oliver, 2012). Previous research has provided a large body of evidence on the physical demands, physiology, injury epidemiology, and kinetics and kinematics of professional tennis (Kovacs, 2006, Roetert et al., 2009b, Roetert et al., 2009a, Ellenbecker et al., 2009, Maquirriain and Baglione, 2015). Subsequently, providing an accurate indication of the key areas to both assess and monitor to understand what may be limiting performance or increasing the risk of injury of young players. It is evident from gaps in the literature that the actual application of this knowledge driving the athletic development of junior players has largely been guided by the existing paediatric literature (Kovacs, 2016, Reid et al., 2003). As previously there has been limited scrutiny of the direct short term or long-term effects of structured S&C training has on the tennis performance within this population of players in early adolescence (Barber-Westin et al., 2010, Fernandez-Fernandez et al., 2015a). Additionally, despite a growing interest in the use of movement screening amongst health and fitness professionals, to the author's knowledge there is limited peer reviewed research reporting on their use within junior tennis. Multiple national and international tennis governing bodies recommend and use screenings such as FMS™ as an assessment and monitoring tool for their top players, but this is not substantiated with scientific evidence regarding the validity, reliability or effectiveness in the sport (Reid et al., 2003). This thesis aimed to be the first research to investigate this topic by establishing the efficacy of the use of movement screenings in junior tennis. This can be initiated by gaining insight into the relationship between screening scores with markers of tennis and physical performance.

Understanding how S&C intervention impacts on the development of the physical competency of young players and subsequent potential knock-on effects to performance, is currently an under researched topic in this specific population. Most of the limited research at U14 level has had relatively homogenous cohorts of elite male adolescent players, creating a gap in the literature regarding young female players and for those working towards becoming elite (Fernandez-Fernandez et al., 2013, Fernandez-Fernandez et al., 2014a, Fernandez-Fernandez et al., 2015a, Fernandez-Fernandez et al., 2015b, Sarabia et al., 2015, Barber-Westin et al., 2010). All the previous studies have reported the acute effects of specific types of short-term (6-8 week) training programmes. Little is known about longitudinal effects of structured S&C programmes in elite junior tennis and the effects on subsequent progression of a player's junior career and eventual transition into senior tennis. To date, only one study to date has followed the physical development of junior players over an extended time period (Kramer et al., 2016a). This thesis will be the first to look at the longitudinal development of players of different training backgrounds and playing levels, with a view to beginning to understand how the presence or absence of S&C during adolescence may influence a player's individual trajectory of development. To be able to apply any of the findings of the above topics accurately within NZ, as a country with its own unique challenges and constraints in comparison to other more successful tennis nations, this thesis must first create an accurate picture of junior tennis in this country. Some examples of these challenges include the lack of indoor and clay court facilities and the geographical isolation of the country meaning the costs of travel to international tournaments are very high. Therefore, this thesis compiled data on the existing training and physical characteristics of NZ players, to allow comparison with both international counterparts and the findings of this research.

1.4 Organisation of thesis

During the planning phases of this thesis, it was evident that there were multiple gaps in the literature regarding application the widely accepted S&C practices, which have been studied and examined in other sports. To establish this and be able to build upon the existing data two comprehensive literature reviews were undertaken (Chapters 2 and 3). These literature reviews explored several topics which presently form the basis of evidence-based practice in junior tennis. These included identifying some of unique demands, complexities and challenges pertaining specifically to tennis, as well as an examination of previous empirical research in this specific population with the objective of creating an accurate picture of the trends and correlations evident throughout this stage of development. The next section was descriptive in nature, using two cross-sectional studies to identify existing trends and correlations present in NZ junior players. In addition, ascertaining differences or commonalities between NZ players and that of international peers reported in previous research. Chapter 4 focused on determining the relationship between physical fitness, growth and maturity characteristics to tennis performance. The second study concentrated on investigating the influence of training characteristics on playing level and National ranking (Chapter 5). The third section of this thesis then sought to investigate how these characteristics interacted with tennis performance over time, using a longitudinal case-study approach monitoring changes in these characteristics across 4-years (Chapter 6). The fourth section was experimental in nature, with Chapter 7 focused on ascertaining the efficacy and relevance of utilising movement screenings as a monitoring and assessment tool in junior tennis, by identifying the relationships between movement competency and performance. Anecdotally, commencing specific S&C training in NZ often occurs around the same time as sport specialisation between the ages of 11-14 years. Therefore, having previously identified the strength (or otherwise) of the relationship between assessment scores and performance in Chapter 7, the following experimental studies of Chapter 8 and Chapter 9 aimed to provide information to guide exercise prescription for players entering an elite training environment for the first time. Firstly, by examining the impact of an FMS training intervention (Chapter 8) and secondly through a strength training intervention (Chapter 9). These two areas were selected as previous paediatric research has highlighted that having sound FMS creates the foundation for all athletic movements and sufficient strength levels underpins nearly all fitness qualities required for physical competency (Lloyd and Oliver, 2012). The last chapter summarises the findings from all these chapters, drawing conclusions and providing general applications for sport and health practitioners working within junior tennis to provide information that contributes to the existing evidence base. Aiming to further improve current practice around the athletic development of U14 tennis players. This process is summarised in Fig 1.1 below.

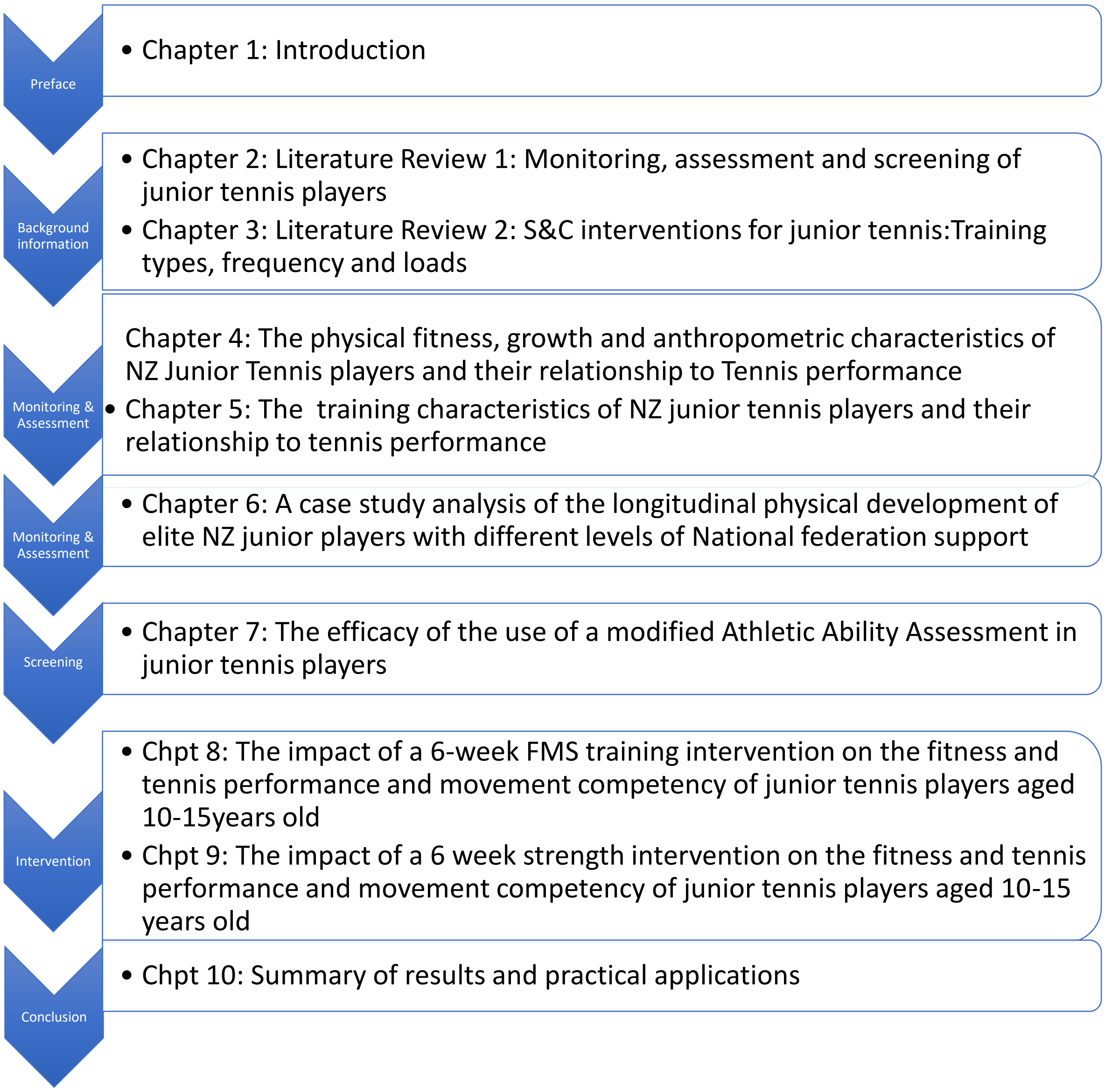


Figure 1.1 Structure of the thesis

Chapter 2 – Literature Review 1: Monitoring, assessment and screening of youth tennis players

2.1 Introduction

It is frequently discussed in paediatric S&C literature that youth athletes should not be treated as "little adults", given the number of biological differences specifically pertaining to adolescence which influences the prescription of exercise (Myer et al., 2013). However, the main objectives of any S&C coach remain the same; to optimise physical potential and prevent injury. To do this successfully knowledge of the specific needs of the sport and epidemiology of injury is required (Turner, 2018). For those working with youth athletes, understanding how growth and maturation may influence their performance and prescription of training throughout adolescence is of equal importance (Malina et al., 2015). This chapter provides an overview of the sport and its unique idiosyncrasies and secondly summarises the literature on these topics in tennis and provides the information from which the current guidelines regarding the monitoring, assessment and screening of junior tennis players are made.

2.1.1 An Overview of Junior Tennis

Tennis has been described as a game of unpredictability, with point length, shot selection, court surface, strategy, match duration, environment and the opponent having the ability to significantly affect the physical and physiological requirements of matchplay (Kovacs, 2009). Match duration averages 1.5 hours (Kovacs, 2007), but can last as long as 5 hours, of which effective playing time has been found to be 20-30% on clay court and 10-15% on hard courts, creating exercise-to-recovery ratios of ~1:2 (Fernandez-Fernandez et al., 2008, Kovacs, 2006), (Groppel and Roetert, 1992). Average point length is 8 seconds, varying from 3-15 seconds, during which 4-15 changes of direction can be made which can equate to over a 1000 changes of direction per match (Fernandez-Fernandez et al., 2014b, Kovacs, 2009, Kovacs, 2006, Cooke et al., 2011). The majority of these movements have been found to be in a lateral direction, 20% forwards and less than 8% backwards, requiring players to be good movers in all directions (Kovacs, 2009). The mean distance covered is 3 m, 80% within 2.5 m of the player's ready position, 10% between 2.5m-4.5 m and fewer than 5% are over 4.5 m. These distances can accumulate to 8-15 m per point and 1300-3600 m per hour dependent on a multitude of factors such as player level, opponent and court surface (Kovacs, 2009, Fernandez-Fernandez et al., 2008), (Roetert and Ellenbecker, 2007). Up to 300-500 high intensity efforts and approximately 1000 shots during a three-set match have been demonstrated (Fernandez et al., 2006, Reid and Schneiker, 2008).

It is has been widely reported that sport specific skills are most important, such as the ability to handle the racquet and stroke skills (Smekal et al., 2001, Reid and Schneiker, 2008). Conflicting evidence exists regarding the relationship between specific physical qualities and performance, culminating in the overall conclusion that performance cannot be attributed to one component of fitness (Ulbricht et al., 2015a, Roetert et al., 1996). As the game continues to evolve to become more dynamic, characterized by rising stroke and serve velocities, it has also been accepted that to be able to compete effectively at elite level, players require high levels of physical fitness (Fernandez-Fernandez et al., 2009, Ulbricht et al., 2015a). It is also unlikely that having high levels of technical, tactical and psychological skill alone without physical fitness will allow a player to reach their full potential (Reid and Schneiker, 2008). Effective stroke production requires efficient movement, repeat sprint ability and explosive force generation, amongst a number of other factors with these physical abilities facilitating the stroke being executed in the first place (Girard and Millet, 2009).

The time period between 15-18 years old in a junior tennis players career is considered essential for player development, a time when it is proposed elite players add physical prowess to an already proficient technical and tactical game (Crespo and Miley, 1998). Players are eligible to participate on the International Tennis Federation (ITF) junior ITF circuit from the age of 13. Elite players compete in progressively higher grade tournaments accessible with increasing ranking, culminating in participation in Junior Grand Slams at the peak of their junior careers (Reid et al., 2007b). The most successful players are often rewarded with wild card entry into senior tournaments which may provide the opportunity to kickstart their professional career and 91% of top-20 ranked boys and 99% of girls go on to achieve a professional ranking (Reid et al., 2007b, Reid et al., 2009a). For most tennis coaches this is evidence enough that this is a successful development pathway for aspiring tennis players and as ranking is based on the points of the best 6 results in any given 12-month period, this can often encourage a quantity over quality approach in achieving the aforementioned benchmark (Reid et al., 2009a). As previously discussed, this can leave limited time for physical development, therefore optimising training time prior to players starting on this circuit may be of key importance in the creating resilience in young players' ability to cope with the demands of heavy tournament schedule competing with players up to 5 years older. For most players this preparatory period is generally between the ages of 10 and 14 years old during the stages of preadolescence and early adolescence.

2.2 Monitoring and Assessment

2.2.1 Growth, Maturation and Relative Age Effect

At the time of this review, the most commonly used methods to assess maturity status were skeletal age and secondary sex characteristics, to assess timing was age at PHV and age at menarche, and to assess both status and timing the non-invasive Mirwald equation (Malina et al., 2015). In terms of reliability and validity, skeletal age as assessed by X-ray using the FELS method is the gold standard and shows high ICC ($r = 0.99$, CI 95% = 0.99–1.00), but is an expensive and largely inaccessible option (Myburgh et al., 2016a). Assessment of secondary sex characteristics in youth is difficult and is generally avoided as it is invasive (Leone and Comtois, 2007). Despite good validity and reliability for self-assessment, (agreement with doctor assessment ($r= .86$ to 0.97, $p \leq 0.05$), this method is often overlooked for privacy reasons (Leone and Comtois, 2007). Assessing timing of specific events (age at menarche or PHV) is dependent on recall or requires measurements over a number of years and therefore unusable in a one-off assessment (Mirwald et al., 2002). This leaves the non-invasive option of the Mirwald equation, which is reportedly inherently reliable, with the ability to predict PHV with ± 1 yr 95% of time, this is believed to be sufficient to measure biological maturity (Mirwald et al., 2002)

It is widely accepted that biological maturation influences physical performance via changes in hormonal profiles creating increases in lean body mass, myelination of motor neurons and enhanced coordination (Lloyd et al., 2015). In turn, this leads to development of a number of physical and physiological variables. (Malina et al., 1991). Across all sports, this variance in growth and maturation has been shown to effect opportunities for youth athletes to participate in sport, be selected into teams, and be identified into talent development programmes (Eisenmann et al., 2020).

Anthropometric analysis of professional tennis players shows a distinct trend towards the most successful being above average height, particularly in male players (ATP, 2018). Similarly, a noticeable trend towards the selection of junior elite British players of both genders on the basis of greater size and/or advanced skeletal maturity has been documented (Myburgh et al., 2016a). Advanced growth and/or maturation providing increased strength and power seems to be an obvious advantage, with increased height frequently correlated to faster service velocity (Bonato et al., 2015, Vaverka and Cernosek, 2013, Hayes et al., 2018). Although this is not empirically proven, it may also play a part in groundstroke velocity and the ability to cover the court (Fernandez-Fernandez et al., 2009, Bonato et al., 2015). This aligns with a meta-analysis across a range of sports, which found differences depending on maturation for anthropometric variables in males (Standard mean difference (SMD) = 0.37–2.31; $p < 0.001$–0.002) and height and body mass in females (SMD = 0.96–1.19; $p < 0.001$). The players with advanced maturation showed higher values in and better physical fitness, highlighting the influence of maturity in the talent identification process (Albaladejo-Saura et al., 2021).

Paediatric literature across many sports has examined the influence of maturation on performance and reported on the trends towards preferential selection of biologically advanced youth (Beunen and Malina, 1988, Pearson et al., 2006, Beunen and Malina, 2008, Malina et al., 2015, Cobley et al., 2014, Cobley et al., 2009). These children are often selected ahead of their peers of the same age due to their superior physical and anthropometric attributes during talent identification or elite team selection events (Ulbricht et al., 2015b, Till et al., 2013, Cobley et al., 2014). This is often linked to chronological age, as relatively older athletes within an age group are likely to be biologically more mature, there is a greater probability that they will present with these physical advantages. In youth sport, this overrepresentation of relatively older athletes has been termed the relative age effect (RAE) (Ulbricht et al., 2015b). This trend has been most frequently reported in ice hockey, volleyball, basketball, rugby and football, with ice-hockey being the one of the first sports to research this phenomenon (Grondin et al., 1984, Cobley et al., 2009). All are sports which potentially benefit from increased size and strength during the ages of 10-14 years old (Cobley et al., 2009, Cobley et al., 2014)

Over the last decade, research in junior tennis has found similar trends (Agricola et al., 2013, Edgar and O'Donoghue, 2005, Loffing et al., 2010, Pacharoni et al., 2014, Ulbricht et al., 2015b). Internationally, at elite U14 level, longitudinal analysis between 2007-2011 found 73.2% of 239 players competing in the World Junior Team event were born in the first two quarters of the year (Agricola et al., 2013). Similarly, analysis of 448 players on the U18 ITF circuit showed a season of birth bias with 59.6% of elite junior players born in the first half of the year (Edgar and O'Donoghue, 2005). The results of both studies seem to be relative to the ITF cut-off date of January 1st and appears independent of regional or climatic influences. Equally, at senior level, 56.2% of the top 500 ATP players between 2000-2006 (n=1027) were found to be born in the first half of the year, indicating that although less significant this trend carries over into professional tennis (Loffing et al., 2010).

National studies by Ulbricht et al. (2015b) and Pacharoni et al. (2014) both analysed the rankings and date of births of cohorts of male players in Germany and Brazil respectively. Ulbricht et al. (2015b) found the better the playing level, the greater the statistical skew towards first half of the year births (e.g., National level – 70.2%, Regional Level - 65.1%, "Ranked players 54.4%), this was less apparent at senior level. Measures of anthropometry and physical performance, highlighted that those still selected at talent identification events despite being born later in the year, were mostly physically like their relatively older peers, indicating "early" maturer's or similar biological ages. This corroborates with that of Pacharoni et al. (2014) whose analysis of 800 players (U12 n=100, U14 n=200, U16 n=200, U18 n=200, ATP= n=100 -Top 100 players) also confirmed the presence of RAE in all youth categories. Their data show 65.2% of the 700 elite (top 100 in age group) players were born in the first two quarters of the year, but a balanced distribution of births between all four quarters among professional players.

The results of all the studies discussed support the notion that at higher levels of selection for talent development programmes or elite teams, to remain competitive younger players must match older players regarding physical fitness performance. Alternatively or in addition to this they must be anthropometrically similar to their relatively older peers to enable this level of performance (Ulbricht et al., 2015a). This may also highlight the influence of physical ability on performance during adolescence and the potential benefit of engaging in physical training at an earlier age to enhance this, although this is an area that requires further research. Data at senior level is slightly contradictory, although it is evident that prevalence of RAE does decrease with age, meaning that often younger or "later" maturing players can "catch-up" (Pacharoni et al., 2014). Incidentally it is also possible that a higher percentage of older/larger players selected at younger ages enjoy greater success as part of a self-fulfilling cycle. As other sports have found, these relatively older players subsequently often secure early advantages such as funding or travel opportunities, which can facilitate their improvement and potentially impact on their development and overall junior tennis career (Malina et al., 2015, Cobley et al., 2009, Till et al., 2013). In contrast, younger and smaller players that are overlooked do not benefit from this, may be subject to the negative side effects of not being selected or funded, both physically and mentally. A potential consequence of this type of oversight may be the danger of a false positive when it comes to the success of relatively older players at senior level. If selectors, coaches and policy makers are mindful of this issue, they would create a more even playing field for those relatively younger or later maturing players. To enable this, further research into longitudinal development of tennis players and the influence of maturation on performance is needed. This will enable testing results to be viewed from a more informed perspective in regards to a player's long term development potential and not just current performance level (Loffing et al., 2010).

2.2.2 Physical testing

Current evidence evaluating the relationship between specific physical attributes and overall tennis performance is conflicting with research showing that skill remains the most consistent predictor of competitive success in junior tennis (Fernandez-Fernandez et al., 2014b, Ulbricht et al., 2015b, Roetert et al., 1992). As the game continues to evolve to become more dynamic, characterized by rising stroke and serve velocities, it has been accepted that to be able to compete effectively at elite level, players require high levels of physical fitness (Fernandez-

Fernandez et al., 2009, Ulbricht et al., 2015a). As research and needs analysis dictates, these testing batteries are generally comprehensive to cover all aspects of fitness, and although variations in protocols exist between National Federations there is a high level of agreement in the methods selected amongst those previously published (See Table 2.1) (Ulbricht et al., 2013, Fernandez-Fernandez et al., 2014b).

As previously discussed, high training volumes seem to be unavoidable for competing at elite level even as a junior, subsequently meaning that training interventions must be as efficient and effective as possible to optimise training time (Fett et al., 2017). The use of physical testing to identify priority areas needing improvement and provide objective measurement of the effectiveness of training programmes is essential at elite level (Reid et al., 2003).

Table 2.1 Fitness testing batteries used by different National Governing Bodies

	Anthropometrics and Flexibility	Speed and Agility	Power	Strength	Endurance
German Tennis Federation (Ulbricht et al., 2013, Fett et al., 2017)	Height Weight Sitting Height BMI Maturity: Mirwald Equation (Mirwald et al. (2002) Sit and Reach Shoulder Flexibility	20m (5m,10m and 20m splits) Tennis Specific Sprints-Shuttle sprint to FH & BH	Countermovement Jump (CMJ) Repetition Jumps Medicine Ball Throws (MBT) Forehand (FH), Backhand (BH) & Overhead (OH)(2kg) Service Velocity	Grip strength Push-up test Sit-up test Back extension test	Hit and Turn Tennis test
Dutch Tennis Federation (Kramer et al., 2017a)	Height Weight Maturity - Redeveloped Mirwald equation by Moore et al. (2015)	5m sprint 10m sprint Spider Test	CMJ Squat Jump (SJ) MBT OH & Reverse Overhead (ROH) (1kg)	Not reported	Not reported
British Tennis (LTA) (Myburgh et al., 2016b)	Height Weight Maturity: Left wrist X-ray, Fels method used to calculate Skeletal Age	20m sprint (5m,10 & 20m splits) FH and BH Agility (U14 & U16) Hexagon Agility Test (U12)	CMJ SJ FH, BH & OH MBT (1kg)	Grip strength	Yo-Yo Intermittent Level 1
USTA (Roetert and Ellenbecker, 2007)	Muscle Length Assessment Body Composition - Skinfold	20yard Dash Hexagon Agility Test Spider Run Test Sideways Shuffle Test	Vertical Jump MBTFH, BH, OH & ROH (2.7kg – 6lb)	Grip Strength Sit Up Test Push Up Test Scapular stabilisation Core Stability Single leg stability	1.5-mile run

Table 2.1 (continued) Fitness testing batteries used by different National Governing Bodies

	Anthropometrics and Flexibility	Speed and Agility	Power	Strength	Endurance
Tennis Australia (Mabon, 2016)	Not reported	20m Sprint (5m, 10m &20m sprints) Mod 5-0-5 agility (left &right)	Vertical Jump	Push up test Chin up test	Multistage Fitness Test (Beep Test)
ITF (Reid et al., 2003)	Height Weight Sum of 7 Skinfolds All flexibility testing to be completed in musculoskeletal screening	20m Sprint 10m Sprint 5m Sprint Movement to FH side Movement to BH side Backwards Movement Test Planned Agility Test Hexagon Test Other: General coordination test Specific coordination test	*Field Tests*: Vertical Jump: 1 and 2 legs Other: Standing long jump/hop Vertical jump with 3-step run up MBT FH, BH and OH MBT *Lab Tests* Elastic potential (from force platform data) Serve Velocity Racquet Velocity in groundstroke production	Push Up Test Grip strength test Other: Max Bodyweight (BW) Dips Max BW Chin ups 3RM Squat or Bench Press divided by BW	*Field Tests* AEROBIC: Multistage Fitness Test (Beep Test) Other: Cooper 12minutes run 1.5-mile test ANAEROBIC: Tennis specific agility endurance test *Lab Tests* VO2 Max Other: Stage Track Test

When it comes to interpretation of physical testing results, existing literature is in general agreement that successful performance cannot be attributed to one predominant physical component but instead to the complex interaction of many physical qualities and metabolic pathways (Ulbricht et al., 2013, Fernandez-Fernandez et al., 2014b, Kramer et al., 2016a). Several older studies analysing these relationships have summarised that performance in several physical components contribute to a predictive model of tennis performance, reinforcing the multifactorial nature of the sport (Roetert et al., 1996, Groppel and Roetert, 1992, Roetert, 1992). In contrast, other research produced around the same time concluded physical performance tests are not good predictors of the ability to play tennis, finding little to no relationships between fitness components and successful tennis performance (Birrer et al., 1986, Roetert et al., 1992). This conflicting evidence may be due to differences in methodology, age and/or homogeneity of the cohorts.

However, significant relationships between individual components and tennis performance have been identified (Roetert et al., 1996, Filipčič et al., 2004, Girard and Millet, 2009, Kramer et al., 2016a, Kramer et al., 2016b, Ulbricht et al., 2015a, Fett et al., 2017, Roetert et al., 1992). At younger ages, speed and agility have more commonly been found to be a predictive factor of performance and having the ability to differentiate between playing levels at U12, especially in male players (Roetert et al., 1992, Roetert et al., 1996, Filipčič et al., 2004, Girard and Millet, 2009, Kramer et al., 2016b, Unierzyski, 2002). This speed advantage is not necessarily sustained into older age groups which may be reflective of the impact of maturation, with strength and power having potentially more influence on today's game at U14 + level (Kramer et al., 2016b). In recent years a shift in the findings of studies of youth players in comparison to older studies may also be a reflection in this change of physicality of the sport. Recent studies in U14 and U16 categories, appear in agreement of the role of upper body power and strength related characteristics in determining junior tennis performance (Ulbricht et al., 2015a, Kramer et al., 2016a, Fett et al., 2017, Girard and Millet, 2009). Ulbricht et al. (2015a) found that across age categories (11-16 years) serve velocity (female $r=-0.43-0.64$, males $r= -0.33-0.49$) and upper body power (female $r= -0.26-0.49$, male $r= -0.20-0.49$) to be the most correlated predictors of youth tennis performance, followed by small-moderate correlations values in tennis-specific endurance. Similarly Fett et al. (2017) found junior Davis Cup players outperformed their regional level counterparts in nearly all areas of physical fitness, particularly in measures of upper body power and strength (serve velocity, medicine ball throws and grip strength). This indicates that increased upper body power and strength capabilities may enable enhanced performance through increased stroke velocities (Fett et al., 2015, Fett et al., 2017, Ulbricht et al., 2015a). These findings align with research which has looked directly at the link between upper body strength and power with serve velocity, showing positive correlations between specific strength markers and serve speed, as well as studies highlighting the positive impact of increasing upper body strength on stroke velocity (Kraemer et al., 2000, Perry et al., 2004).

Longitudinal studies in youth tennis suggests slightly contradictory results following the physical development of the top 60 Dutch players between the ages of 13-16 (Kramer et al., 2016a, Kramer et al., 2017a, Kramer et al., 2016b). Similar to those discussed previously in, the first study in three of the four parameters measured (lower body power, speed and agility), higher ranked girls outscored lower ranked at U14 level and this difference remained the same at U15 and U16 (Kramer et al., 2016a). In contrast, no significant difference was found between level of performance and upper body power for females. However, this component saw the greatest improvement with age (17%). No relationship was found between any of the four components and ranking in male players. The authors speculated that this lack of correlation this may be created by the relative homogeneity of this cohort. This suggests that the physical fitness required to a be top 60 Dutch junior male player, does not differ significantly between the number 1 ranked and number 60 ranked player, and not that there are no relationships in existence (Kramer et al., 2016a).

The second study used a more heterogeneous group of 256 males of elite and sub-elite players age 10-15 years measuring height, body mass, lower limb explosive strength (via vertical jump) and 5m speed over 5 years (Kramer et al., 2016b).The results showed elite players to be faster than sub-elite players especially from the age of 10-13 years, and lower limb explosive strength was a predictor of sprint performance. Differences in speed at age of 14-15 years were negligible, however the selection process in the Dutch talent identification system follows a pyramid structure, with fewer players tested with every year of age (e.g., 300 players aged 10 and 62 players at age 15). This reduces the statistical power of the analyses at older ages and potentially creates a similar issue of homogeneity at older ages, not allowing for those deselected or who had a dropped out during the 5-year period (Kramer et al., 2016b). More recently, the same author carried out the same investigation in females players (n=167) and their findings followed a similar pattern to the male cohort, with elite players being faster between the ages of 10-14 years old but no significant difference from the age of 14 (Kramer et al., 2021). In this cohort, it was possible to predict sprint performance based on age, height and lower limb strength performance, suggesting maturation may play a bigger part in sprinting ability in females than males in this age group (Kramer et al., 2021).

The same research group later examined a similar cohort of 86 players ranked in the Dutch Top 30 at U13 (Kramer et al., 2017a). This study looked at the predictive ability of physical variables and tennis performance at U13, but with a view to ascertaining whether physical performance at this age could predict tennis performance at U16(Kramer et al., 2017a). The results showed that upper body power explains 25% of boys ranking, but this did not correlate to performance at U16. Whereas, for girls the only physical variable which contributed to ranking at U13 was age at Peak Height Velocity (APHV), in that the earlier a girl reached APHV the better her tennis performance and this did correlate with U16 ranking (Kramer et al., 2017a). Indirectly it could be argued that this link between maturity and performance is potentially still reflective of the importance of strength and power in youth tennis, as it is possible that the successful performance of the earlier maturing girls came as result of the greater forces they could be produce because of their superior height and mass.

Although the evolution of forces and velocities present in today's game are clearly significantly greater than 20-30 years ago, the reason for this cannot be necessarily quantified (Cross and Pollard, 2009). Improvements in technology, sport science and training methods are just a few factors that may have influenced these changes. However, it is undeniable that the result is physical demands are higher, requiring players to be better athletes. Therefore, when it comes to contemporary talent identification, perhaps placing greater importance on the athletic potential of young players is more important today than perhaps in previous generations. It is also evident that having high levels of technical, tactical and psychological skill alone without a good all-around level of physical fitness will not allow a player to reach their full potential (Reid and Schneiker, 2008). Many national governing bodies choose to do physical performance assessments on specifically targeted talent identification days providing a snapshot view of a player's athletic potential (Fernandez-Fernandez et al., 2014b). Despite a need for good all-around physical ability, literature analysed for this review suggests that some fitness components may have a stronger influence on performance than others within specific age groups and genders (Kramer et al., 2016a, Sheppard and Young, 2006). With this in mind, interpretation of testing results, in addition to the previously discussed impact of maturation on physical performance in young tennis players, should enable creation of a clearer picture of what a young player's actual physical potential may be (Kramer et al., 2017a, Kramer et al., 2021).

2.3 Screening

Another widely accepted part of the long-term development of a youth athlete is movement screening, which forms an ongoing part of the assessment and monitoring of an individual's current physical condition and readiness to train as they continue to grow and develop (Cook et al., 2006, Cook et al., 2014, Bishop et al., 2015, Ransdell and Murray, 2016). In contemporary elite sport, screenings are often completed in two forms; by the medical team in the form of musculoskeletal screening and by the S&C team in the form of a fundamental movement screen (Kritz, 2012, Ellenbecker et al., 2015). Part of the focus of this is on the latter of the two screenings, specifically the efficacy of this form of screening within junior tennis populations. This type of screening was originally designed to act as an ecologically viable method of assessing movement quality under real-world conditions and considered to bridge the gap between pre-participation medical screening and performance (Kraus et al., 2014, Cook et al., 2006). Functional movement has been defined as "the ability to maintain a balance between mobility and stability along the kinetic chain while performing fundamental patterns" (Mills 2005). Inherently this requires competence in multiple aspects of physicality including strength, flexibility, endurance, coordination and balance, which are also key to sport specific skills and performance (Okada et al., 2011). Consequently, S&C practitioners therefore seek to develop competency during early childhood and preadolescence, to allow progression to the more complex movement demanded by elite sport (Lloyd et al., 2013). Many S&C practitioners in tennis now commonly seek to gauge the physical competency of their athletes through movement screening assessments as part of a full testing battery, in order to guide programme prescription and volumes (Kritz, 2012, Bishop et al., 2015, Ransdell and Murray, 2016). However, there is little published information about the use of movement screenings within tennis and particularly in junior tennis, despite it being widely accepted as common practice amongst sport and health professionals (Kritz, 2012, Kraus et al., 2014, Bishop et al., 2015, Song et al., 2014). Additionally, multiple national and international governing bodies recommend their use as an assessment and monitoring tool for their top players (Kovacs, 2016). This is not yet substantiated with scientific evidence regarding the validity, reliability or effectiveness in tennis (Reid et al., 2003).

Several field based protocols have been developed with the most widely accepted protocol being the Functional Movement Screen™ (FMS™) (Cook et al., 2006). However, it doesn't necessarily account for the higher velocities and loads of sport (McKeown et al., 2014, Cook et al., 2006). Further research therefore sought to build upon the underlying principles of the FMS™ attempting to gain greater specificity for the athletic population. Two such protocols, The Movement Competency Screen (MCS) (Kritz, 2012) and the Athletic Ability Assessment (McKeown et al., 2014) were developed in New Zealand and Australia respectively. These protocols attempt to create assessments with the same goal of allowing practitioners to evaluate their athletes effectively and efficiently without the use of expensive and largely inaccessible equipment (Wilke et al., 2017).

The MCS was created with guidance of 42 Health and Sport practitioners (22 S&C specialists and 20 physiotherapists) who were surveyed to ascertain the structure and function of the protocol. The objective was to create a screening protocol more closely aligned with sporting movements. It resulted in the inclusion of 6 movement tasks identified as being part of activities of daily life as well sport and sport-specific training (Kritz, 2012). Reliability was explored during the development process finding near perfect intra-rater agreement and substantial interrater agreement, but no other studies using the MCS further explored this or the validity of the protocol (Kritz, 2012). Therefore, it is unknown whether the enhanced sport specificity of the MCS comes with superior ability to predict athletic performance or injury. The authors found practitioners using their protocol reported it to be effective for several reasons (Kritz, 2012). Particularly, in gaining an initial overview of the athlete's movement patterns that they anticipate loading in the gym and during conditioning. Subsequently creating a language that both S&C and medical professionals can communicate with as regarding loading safely to optimise athletes physical ability at that time (Kritz, 2012).

The Athletic Ability Assessment (AAA) was also developed with the aim of being more specific to the athletic movement skills that typically underpin exercises used for physical development within team ball sports (Woods et al., 2015, McKeown et al., 2014). It could be argued that these movements are also relevant to other individual ball sports as well. The authors highlighted that sport performance requires a lot more demanding movement ability than either the FMS™ or MCS includes, as both screenings are devoid of any loads or velocity that are comparable with sporting demands (McKeown et al., 2014). Sport presents greater complexities of movement, including single leg jumping, landing and total body control under increasing loads (Besier et al., 2001). Athletes are statistically more likely to get injured performing a movement of this nature than a slow controlled movement (McKeown et al., 2014, Besier et al., 2001). The inclusion of these types of movements in the AAA could mean that this protocol may provide greater validity and better insight to how their athletes may cope with the demands of their own sport. However, to the authors knowledge, there have been no peer reviewed studies investigating the reliability or validity of the AAA, or any attempts to analyse the predictive ability of this screening to performance or injury risk.

Other methodologies involving the biomechanical analysis of plyometric movements such as the Landing Error Scoring System (LESS), Single leg landing Assessment and Tuck Jump Assessment have been designed specifically to outline the risk of lower limb injury, particularly ACL trauma which can be career limiting or ending for many athletes (Padua et al., 2009, Myer et al., 2008, Jones et al., 2014). However, these assessments are largely carried out in addition a full movement screening, as opposed to being the sole source of information about an athletes physical competency (Bishop et al., 2015)

2.3.1 Rationale for Movement Screening

The rationale behind movement screenings is often multifaceted, as clearly the act of simply carrying out movement screening will not directly result in a reduction of injury or performance enhancement (Kritz, 2012, Kiesel et al., 2011, McKeown and Ball, 2013, Parchmann and McBride, 2011). It is the interpretation and subsequent use of the information that will dictate the effectiveness of the movement screen.

In recent years, several different field based protocols have been developed with the most widely accepted protocol being the Functional Movement Screen™ (FMS™) (Cook et al., 2006). In the literature analysed in this thesis, this is the only protocol to have received extensive investigation in regards to validity, providing data on how the results of this type of screening can be extrapolated and interpreted (Brigle, 2010, Chorba et al., 2010, Frost et al., 2012, Lockie et al., 2015b, Parchmann and McBride, 2011). This research has been completed across multiple sports and populations, with particular interest in its ability to predict injury risk and performance in sport (Kiesel et al., 2007, Chorba et al., 2010, Frost et al., 2012, Lockie et al., 2015b, Parchmann and McBride, 2011, Warren et al., 2013, Anderson et al., 2015). Although there is some disparity between studies, a moderate amount of scientific evidence exists behind the use of total score predicting injury risk, especially when incorporating a cut-off/threshold score <14, many studies were able to show that athletes scoring below 14 were at significantly higher risk of injury than those scoring above 14 (Chorba et al., 2010, Garrison et al., 2015, Kiesel et al., 2007, Kiesel et al., 2014, Samson et al., 2015). Conversely, there is increasing evidence to the contrary, making it less clear as to the real predictive value of this screening with regards to injury (Warren et al., 2015, Bahr, 2016, McCunn et al., 2016).

Opinion regarding using total score on the FMS™ to predict athletic ability is also divided (Parchmann and McBride, 2011, Kiesel et al., 2011). Most studies have failed to find any direct correlation between screening results and sporting performance (Okada et al., 2011, Lockie et al., 2015b, Parchmann and McBride, 2011). A select number of studies have found indirect association between movement quality and elements of performance, when looking at the relationship between individual components of the screening (McGill et al., 2012, Kraus et al., 2014).

Current evidence is equivocal on the validity of the FMS™, this may be because there is not yet enough data on this topic to provide a definitive answer. Additionally, limited literature substantiating the use of other protocols such as the Movement Competency Screen (MCS) (Kritz, 2012) or Athletic Ability Assessment (McKeown et al., 2014), prevents direct comparison between protocols to justify selection of one screening method over the other.

In the absence of a collective agreement on the use of movement screens it is important to consider their limitations, both in terms of the protocols themselves and how the results are interpreted (Gamble, 2013, Bahr, 2016). Firstly, limitations within the delivery and administration of screenings exist in the context of the amount and consistency of instruction participants receive (Gamble, 2013). Lack of information regarding scoring criteria and familiarisation with the exercises has been shown to produce false negatives, as participants were able to correct movement when informed of the scoring criteria and therefore likely not to be reflective of a true dysfunction (Frost et al., 2015). Interpretation can be limited by the scoring criteria, often too gross to discriminate small amounts of variation and perhaps not sensitive enough to measure change across a short time period or differentiate between athletes with small variation in ability (McCunn et al., 2016). Thirdly, it appears movement screenings have limited use as a predictive tool for injury or performance (Bahr, 2016, McCunn et al., 2016, Howe and Bishop, 2022). Multiple methodological flaws and variation have been highlighted in literature purporting use FMS™ as an injury prediction tool (McCunn et al., 2016). Flaws include poor injury definitions, lack of evidence between poor performance in a screening marker and injury and insufficient injury follow up duration (Bahr, 2016). This is in addition to variation such as participant numbers, sport, and playing level amongst other factors (McCunn et al., 2016). Therefore, it appears movement screenings have limited ability to predict injury but may be possible to identify athletes at greater risk (Howe and Bishop, 2022, Hewett et al., 2005, Padua et al., 2009).

This does not mean these screenings do not have a place within LTAD with the premise that movement screens provide assessment of strength, flexibility, coordination, balance and proprioception in a time efficient and low-cost manner seems to be a logical one. However, the used of movement screens requires further investigation to enable their use in the right context. As these components are key for enabling basic movement proficiency (Bishop et al., 2015), understanding an individual's current level of competency at any given time, theoretically, can only enhance the evidence-based practice of S&C coaches. Tennis requires complex coordination of the kinetic chain (Roetert et al., 2009a), gaining an empirical understanding of relationships between movement quality and performance, theoretically should enhance development of young players by providing coaches data to better inform interpretation of screening results. It should be considered that that purpose of a movement screening is not to diagnose why a poor movement exists but to highlight it (McCunn et al., 2016). This may be particularly useful for young or inexperienced athletes, to provide a baseline indication of an athletes baseline movement quality before commencing an S&C programme(Howe and Bishop, 2022)

In the absence of published research on the use of movement screens in tennis, the literature below provides insight as to how they may be able to add value to the development of junior players. This is based on alignment with the theoretical constructs evident in LTAD literature and the specific characteristics pertaining to junior tennis which make it unique in comparison to other sports.

2.3.2 Rationale for Movement Screening in Tennis

Intuitively S&C practitioners often feel obligated to attempt to fix movement discrepancies and raise the level of basic competency when working with athletes for the first time. This is to enable them to deal with the complexity and loads of their sport (Woods et al., 2015, McKeown et al., 2014). As previously discussed, FMS development has been identified as a priority during early childhood years, and that it is not happening as naturally as with previous generations (Lloyd and Oliver, 2012, Wrotniak et al., 2006, Tompsett et al., 2014).

Youth athletes should be able to transition smoothly from the "training to train" stage of middle childhood and early adolescence to the "training to compete" stage through gradual increments in structure and volume (Kovacs et al., 2008a). Anecdotally in NZ, players and coaches often do not dedicate time to physical training until the player has reached a level where they have started to take the sport more seriously or even specialise. Therefore, players are already in the "training to compete" stage and likely to be preadolescent or older. This is further corroborated by experts such as Mark Kovacs who stated that young tennis players seldom reach optimum athletic development, due to a number of reasons specifically pertaining to the structure of junior tennis (Kovacs, 2016). The common denominator of these reasons is that often young players follow the same principles as adults, both with regards to training and competition. Young players will often follow tournament schedules similar to professionals, with strong focus on outcome goals, high formal competition to training ratios and training volumes that are inappropriate for their age, without spending enough time acquiring fundamentals (Kovacs, 2016).

When entering this stage with the aforementioned demands, if mastery of FMS such as jumping, landing, running, lunging, squatting etc. has not been gained during childhood, the athletes ability to participate in training activities based on these key skills is limited (Balyi and Hamilton, 2004). It could then be argued in the case of an older and physically incompetent athlete, focus on the development of FMS may be taking up valuable training time in what is an already busy schedule with limited time for physical sessions (Fett et al., 2017). Instead a competent athlete could be focusing on aspects of physical development more aligned with their biological age and more directly linked to performance in sport and development of sport specific skill e.g. hypertrophy, power or endurance (Lloyd et al., 2014). As movement screening results provide a snapshot of the athlete's neuromuscular control and stability throughout fundamental movement patterns at that time, it can indicate to practitioners the appropriate loads and complexity of training exercise the athlete may be able to tolerate (Chorba et al., 2010, Howe and Bishop, 2022). Research from other sports has suggested that this is where movement screenings can add value, with regards to aiding programme prescription for athletes entering an academy or elite environment for the first time (Parsonage et al., 2014, Kritz, 2012, Howe and Bishop, 2022). As this is yet to be examined in tennis, further research is warranted.

Another factor to consider, is often better players are fast tracked to higher levels of competition at a younger age, bringing increased physical demands and potential injury risk for those ill-prepared for this change in intensity (Johnson and McHugh, 2006, Fernandez-Fernandez et al., 2009, Reid et al., 2007b). Unlike team sports, players can start playing on professional tours (ATP/WTA) as young as 14 years old (Reid et al., 2009a, Reid et al., 2007b), thus accelerating the need for basic FMS to be mastered at an earlier age.

It is thought that through the process of LTAD happening gradually over time enables players to be able to train efficiently and effectively with reduced risk of injury, promoting steady progress into professional sport (Parsonage et al., 2014). In a review of sport and health literature, poor movement competency has been identified as having the ability to negatively impact both injury frequency and severity across numerous sports (Kiesel et al., 2011).

Most documented injuries in junior tennis can be defined as overuse injuries, including tendinopathy, chronic muscles strains and joint instability caused by repetitive microtrauma characteristic of the sport (Abrams et al., 2012, Ellenbecker et al., 2009, Hjelm et al., 2012, Bylak and Hutchinson, 1998, Kibler and Safran, 2000). Junior players are less likely to suffer from true tendinopathy before the age of 15, but instead are at greater risk of apophyseal conditions and growth plate related injury (Pluim et al., 2015, Hjelm et al., 2012, Kibler and Safran, 2005). High training volumes from a young age are widely accepted as a key to success, and this in combination with demanding year-round tournament schedules, puts all players, especially young elite players at high risk of this type of injury (Pluim et al., 2015). Excessive focus on training and competition at young ages as previously mentioned, instead of FMS development has been shown to lead to burnout and overuse injury (DiFiori et al., 2014). Additionally, there is an increased likelihood of overuse injury during peak height velocity (PHV), when the articular surfaces, physes and apophyses are less resistant to force than mature or pre-pubescent bone (DiFiori et al., 2014). Previous research has highlighted that reduced range of motion, decreased neuromuscular control and strength can impact on movement quality and increase the risk of overuse injury (Hewett et al., 1999). Additionally, low flexibility in adolescent populations also exacerbates this risk especially during growth, when there is a discrepancy between bone and muscle length (Kibler and Safran, 2005). In tennis the areas most affected by this discrepancy are the lower back, knee and shoulder (Kibler and Safran, 2005). It is well established, that the repetitive nature and complex biomechanical demands of the sport can result in characteristic sport–specific injury patterns and musculoskeletal adaptations, some of which may also be identifiable through movement screening (Ellenbecker et al., 2009, Abrams et al., 2012, Hjelm et al., 2012). Therefore, it is hypothesised that gaining this type of information before prescribing programmes would be mutually beneficial for the athlete and coach. Diagnosing injury is outside of the remit of the S&C practitioner, but understanding what may predispose their athlete to injury in their particular sport is essential and are often can be addressed through correct exercise prescription (Clark and Lucett, 2010). Hypothetically, remaining free of injury and being physically capable of meeting complex physical demands of elite sport enables players to optimise time on court for skill acquisition as well technical and tactical development, which in turn should provide the player with their best opportunity for success. Currently, this theory is largely unsubstantiated due a lack of research taking a top-down approach. Therefore, we do not have information to prove or disprove that tennis professionals with good movement quality, FMS and without asymmetry are any more successful or have a reduced rate of injury than those who do not.

2.4 Summary

It is apparent that as tennis is a sport without fixed time limits, S&C coaches must attempt to prepare their athletes for a whole spectrum of different competitive scenarios and to have good all-around athletic ability to maximise performance (Roetert and Ellenbecker, 2007, Kovacs, 2007). Analysis of the growth characteristics of junior elite players, has drawn attention to the preferential selection of biologically advanced athletes, creating similar trends in RAE as seen in other sports (Myburgh et al., 2016b, Ulbricht et al., 2015b, Agricola et al., 2013). Investigation into physical testing performance of young players has shown superiority of these relatively older athletes, particularly in measures of strength and power (Kramer et al., 2016a, Kramer et al., 2016b). Additionally, these physical advantages also appear to provide an advantage when it comes to tennis performance, although this is not necessarily sustained into later adolescence (Fett et al., 2017, Ulbricht et al., 2015b). On this basis, when using physical testing as part of talent identification or selection event or for those involved in the LTAD of a player, it is suggested that scores are interpreted in relation to maturational age to avoid misconstruing data of players with the same chronological age (Cobley et al., 2014, Cobley et al., 2009). Secondly, given the multifactorial nature of tennis, the use of a comprehensive testing battery is essential to highlight strengths and weaknesses of young players, to enable tailored individualised fitness programmes optimising limited available physical training time (Ulbricht et al., 2013). Additionally, there is a substantial body of evidence regarding the main risk factors pertaining to the common mechanisms and types of injury identified previously and discussed as most prevalent in tennis (Kibler and Safran, 2000, Abrams et al., 2012, Ellenbecker et al., 2009, Hjelm et al., 2012, Kibler and Chandler, 2003). This chapter has highlighted a lack of empirical evidence regarding the use of movement screens within tennis. Without placing value on the supposed predictive ability of movement screenings, it could still be theorised that movement screening could be used as a form of educated risk assessment. This could be achieved by focusing on looking for the presence of relevant risk factors and using this information to prescribe preventative or corrective exercise programmes for the benefit of the athlete's overall health and wellbeing (Ellenbecker et al., 2009, Kibler and Chandler, 2003). This may be of even more significance among the population in question in this thesis, due to the constantly evolving physiological state of growing adolescents (Malina et al., 2015).

Monitoring, assessment and screening of athletes provides vital information to guide intervention into the physical development of young players, to optimise performance as well their health and well-being. The previous research reviewed on these topics has begun to create a picture of the influence of maturation and physicality on junior tennis performance, although this information has come from a relatively limited selection of studies. Therefore, it would be beneficial to build upon this information and specifically for tennis in NZ, understand whether the same trends exist in this country, related to it its own unique infrastructure and challenges. Despite, a body of research on medical musculoskeletal screening and assessment, there is a clear gap in the research as to the efficacy of FMS in junior tennis. Further investigation may contribute to informing the process of developing and assisting young players in the optimisation of their potential.

Chapter 3 – Literature Review 2: Existing research on Strength and conditioning interventions for junior tennis; training types, frequency and loads

3.1 Introduction

There is a growing body of evidence that suggests significant positive impacts of S&C for tennis performance (Reid and Schneiker, 2008, Fernandez-Fernandez et al., 2009, Kovacs and Ellenbecker, 2011b, Roetert et al., 2009b). To provide effective training interventions, implicit understanding of the current needs of the athletes through assessment and monitoring is essential (Turner, 2018, Bishop et al., 2015). Quantification of training loads is an important part of monitoring, enabling effective periodisation of training programmes for high performance athletes (Murphy et al., 2015b). It is evident S&C practitioners working in tennis have an array of additional unique considerations which have large implications on designing and implementing training programmes (Novak et al., 2013). Unknown match lengths and weekly match volumes, multiple different playing surfaces and sometimes weekly international travel requirements as a few examples. Furthermore, safe and effective administration of physical training interventions in youth athletes requires practitioners to have a sound grasp of how an athlete may respond to load, recover and subsequently adapt (Murphy et al., 2013). Where possible, best practice may involve utilising interventions already established to be valuable within the specific population in question to optimise limited training time. This review aimed to summarise existing research on S&C training interventions and common training characteristics in tennis which are currently providing the evidence base guiding those working in the development of youth players.

3.2 Current recommendations on frequency and volume of training for junior players

Recommendations for the training hours required for a junior performance player varies vastly throughout different countries and training centres, with a lack of agreement on total volume, as well as the division of training time between on court and S&C activities (Baxter-Jones and Helms, 1996). It is apparent that there is not a single clear path for developing a top player as the best players have originated from all over the world, grown up playing on different surfaces, in diverse climates, taking various competitive routes to success (Reid et al., 2009b). Limited empirical longitudinal evidence exists to enable understanding of the impact physical training on the development of a players' physical ability, subsequent progression of their junior careers, and eventual transition into senior tennis (Kramer et al., 2016a). Identifying priority training focus is made more difficult by the sport being underpinned by the multifaceted interaction between skill and physical ability, as well as technical, tactical and psychological factors all contributing to successful tennis performance (Reid and Schneiker, 2008, Ulbricht et al., 2013).

It is well known that a great amount of time is devoted to technical and tactical training in tennis averaging 15-20+ hours per week, which itself creates a high volume of physical loading (Fernandez-Fernandez et al., 2015a, Sarabia et al., 2015). This is the amount of time suggested by the ITF that junior players dedicate to skill development, but there is a lack of data identifying optimal specific physical training volumes to support these tennis training loads in young athletes (Reid et al., 2003). The United States Tennis Association's (USTA) recommendations on this subject are based on a number of factors; including maturational age, training age and training goals (Ochi and Campbell, 2009). Frequency, volume and intensity are presented on a progressive scale starting with 1-3 days per week of 30 minutes sessions during prepuberty to 4-6 days per week of 60-90 minute sessions post puberty (Ochi and Campbell, 2009). In alignment with other paediatric literature , it is suggested that where possible U14's training is matched to the players biological age and physical needs associated with that stage of maturation, with specific focus on factors that most limit tennis performance (Unierzyski, 2005).

3.3 Analysis of the training characteristics of elite junior players

Empirical research analysing physical training characteristics for junior tennis players is scarce (Sánchez-Muñoz et al., 2007, Fett et al., 2017, Fett et al., 2015, Unierzyski, 2002). Sánchez-Muñoz et al. (2007) and Fett et al. (2017) both focused on examination of the best U16 players participating in Junior Fed Cup (JFC) and Davis Cup (JDC). Training volumes reported in this study are shown in Table 3.1. The first study reported only total training volumes; however it was not disclosed whether this was inclusive of physical training or only referred to tennis training alone. Both studies reported similar total training hours, but Fett et al. (2017) reported that total time was divided between 15.1 ± 4.3 hrs tennis practice and 7.6 ± 3.7 hrs to physical development. The latter study also compared the data of their elite players to their regional level counterparts. Although comparable in regards to ratio of tennis to physical training, total volume was significantly higher in elite players (ES=1.23-1.66) than that of their regional level peers (Fett et al., 2015). This supports the theory that high training volumes are needed to compete at elite levels. Within the elite group, strong relationships were found between total training volume and tennis ranking (r=0.78), as well as age with physical training volumes (r=0.82) and total training volumes (r=0.62) (Fett et al., 2017).

Table 3.1 Training characteristics of U16 players in previous research

U16 studies	Sample size and Playing level	Elite tennis training volumes (Hours per week) (mean ± SD)	Elite physical training volumes (Hours per week) (mean ± SD)	Sub elite tennis training volume (Hours per week) (mean ± SD)	Sub elite physical training volumes (Hours per week) (mean ± SD)
(Sánchez-Muñoz et al., 2007)	n=123 57 male 66 females Level: Junior Davis Cup & Fed Cup players Age:	Top 12 players Males=25.6 ± 2.1 hrs Females=23.2 ± 2.3 hrs	Not reported	Ranked <12 Males=22.1 ± 2.9 hrs Females= 20.4 ± 2.6 hrs	Not reported
(Fett et al., 2017)	n=166 12 Davis cup players (male only) – Elite 2 samples of "regional squad" – Sub Elite Sample 1 n=60 males & n=47 females Sample 2 n=59 males	Davis Cup players (male only) n=12 15.1 ± 4.3 hrs	Davis Cup players (male players) n=12 7.6 ± 3.7 hrs	Regional squad n=166 (119 males & 47 females) 9.8 ± 3.7 hrs	Regional squad n=166 (119 males & 47 females) 4.5 ± 2.2 hrs

These relationships were not reported amongst regional level players, perhaps reflective of the gradual process of specialisation with better players dedicating more time to development of their game as they get older (Balyi and Hamilton, 2003). Research in adult populations indicates that the correlation between training hours and age may be a trend that continues into adulthood. Hornery et al. (2007) reported an average of 32 hours per week in elite males during out-of-competition phases, significantly higher than those reported in adolescent populations.

Less empirical information is available regarding U14 and U12 players. The data from three previous studies is reported in Table 3.2 below. Both U14 studies reported similar total training volumes (Pluim et al., 2015, Unierzyski, 2002), which corroborates with training hours recommended in an International Tennis Federation publication, of 10-12 hours per week age 12, progressing to 15 hours at 14 is appropriate for elite players during this stage of development (Unierzyski, 2005). As with U16 level, noticeable differences in training hours were found between the best 15 players and those less successful at U14, in a study analysing both the physical and training characteristics of 83 of top players in Europe (Unierzyski, 2002). The players were categorised into two groups based on ranking as junior and subsequent ranking as a senior player 8 years later (Table 3.2) (Unierzyski, 2002).

Table 3.2 Ranking and Training characteristics of participants in U14 studies

U14 & U12 studies	Sample size and Playing level	Elite tennis training volumes (Hours per week) (Mean ± SD)	Elite physical training volumes (Hours per week) (mean ± SD)	Sub elite tennis training volume (Hours per week) (mean ± SD)	Sub elite physical training volumes (Hours per week) (mean ± SD)
(Pluim et al., 2015)	n=73 players All players part of the high-performance programme run by the National Dutch federation – Royal Dutch Lawn Tennis Association (KNLTB) Age: 12.0 ± 1.1	Males n=45 Total: 11.6 ± 0.6 hrs Tennis training: 9.3 ± 0.7 hrs Matchplay: 2.2 ± 0.7 hrs Females n=28 Total= 11.0 ± 1.0 hrs Tennis training= 8.7 ± 0.7 hrs Matchplay= 2.2 hrs ± 0.9 hrs	Not reported	No comparison group	No comparison group
(Unierzyski, 2002)	n=19 Group 1 n=12 European U14 ranking <5 at 12-13 years old Group 2 n=7 European U14 ranking >15 at 12-13 years old	12.5 hrs	4-6 hrs (reporting unclear)	10 hrs	2hrs above mean :6-8 hrs? (reporting unclear)
(Söğüt et al., 2019)	n=119 Males n=68 Females n=51 Nationally ranked Turkish players Age 10.9 ± 0.7 yrs	Males: 6.6 ± 2.1 hrs Females: 7.5 ± 2.5 hrs	Males: 3.3 ± 2.2 hrs Females: 2.7 ± 1.9 hrs	No comparison group	No comparison group

Group 1 consisted of players who were most successful at U14 although were lower ranked as senior players. The results suggested it was advanced maturation and tennis experience, but this did not necessarily translate to senior success (Unierzyski, 2002). The authors also speculated that the more balanced training programmes of Group 2 players (most successful at senior level), enabled them to cope with higher loads at a later age and attain better results. This study was not without limitations, firstly data presentation was ambiguous with no accurate report on physical training hours. Secondly of 83 players analysed at U14 only 19 could be followed at U21, resulting in a relatively small sample size with uneven split between groups. Thirdly, conclusions were drawn on two snapshots of information, 8 years apart. Information regarding training and assessment of physical ability was only gathered at ages 12-13, and ranking analysed at ages 19 - 21 years, with no information provided on the time in between. Subsequently, the relevance of players early training habits and physical prowess is unknown. There is also a lack of clarity on the reasoning behind why only 19/83 players were selected for analysis at U21. Perhaps overlooking key reasons as to why some players dropped out of the sport and never achieved a senior ranking despite early promise. It is recommended that further research is needed to isolate which of the multiple factors investigated were responsible for the future success of Group 2 players (Unierzyski, 2002)

Another key area lacking scientific evidence is the impact of tennis training frequency on the fitness characteristics of adolescent players. Sanchis-Moysi et al. (2011) specifically looked at the effects of playing frequency on certain physical components in prepubertal boys. They found those playing tennis 2 days per week had superior aerobic power ($p \leq 0.05$) and reduced body fat percentage ($p \leq 0.05$) in comparison to non-active controls (Sanchis-Moysi et al., 2011). Data from the study showed the latter of the two also accounted for superior running and jumping performance, suggesting training 5 days per week may further improve these differences (Sanchis-Moysi et al., 2011). Given the superior physical performance and significantly higher total training volumes of elite players in comparison to lower ranked players (Fett et al., 2017, Ulbricht et al., 2015a) it is not unreasonable to suggest the positive influence of the higher training frequencies of elite tennis on fitness (Fett et al., 2017, Ulbricht et al., 2015b, Kramer et al., 2016a, Sánchez-Muñoz et al., 2007). However, widespread variance in training focus and intensity, in addition to a lack of control within these studies for participation in other physical activity amongst other factors, makes this difficult to quantify or isolate.

3.4 Tournament Loads

Tennis is one of few sports whose competitive seasons runs through the majority of the calendar year, with important peak events throughout (Novak et al., 2013). These are played indoors and outdoors, on clay, grass, carpet and hard court surfaces, with large temperature and altitude variations, (Fernandez-Fernandez et al., 2010). Matches have been known to last from minutes up to 11 hours and 5 minutes (Wimbledon, 2010), and if weather dependent across multiple days. Tournament schedules at elite level places large travel implications on players, who are expected to move countries and even across continents to compete. This requires adjustment to time zones, environmental conditions and the general fatigue that might come from travelling itself (Turner, 2018). Due to the knockout structure of tournaments, a player and coach will not know how many matches will be played in any given week, requiring large flexibility in any planning and periodisation of training. Ranking determines the level of tournament in which a player can compete, and making the cut is dependent not only on their ranking but on that of others entered in that week. This element of game uncertainty leads to unclear long-term tournament scheduling. At senior level, those who have previously experienced poor form may add tournaments onto their schedule. It is common to see top 10 players competing in only 18-22 tournaments a year, where others may enter more than 32 tournaments. This results in less recovery and training time, occurring similarly at senior and junior level (WTA. 2016). This can make periodisation of young player's physical development challenging, often lacking sufficient time to maximise a players genetic potential (Novak et al., 2013, Kovacs, 2016).

The reason for this time restriction is multifaceted, not only is the available time for training blocks often limited by the presence of multiple tournament blocks but maintaining positive adaptations during these blocks is also challenging (Murphy et al., 2014). For young players, due to the demanding travel requirements, tours are often 4-6 weeks in length for both economical and logistical reasons. During this time players often lack access to appropriate facilities, coaches or support for physical training (Kovacs et al., 2007). Lack of supervision over the course of these tours can lead to poor or inadequate adherence to prescribed maintenance programmes and in competitive players noticeable decrements in speed, power and aerobic capacity have been observed post tours(Kovacs et al., 2007, Murphy et al., 2014). Understanding the impact of training and match loads prior to and during a tournament block, is important for coaches to be able to accurately prescribe programmes that attempt to preserve physical capacities during a competition phase (Murphy et al., 2015b, Murphy et al., 2014).

To data only two studies by(Murphy et al., 2014, Murphy et al., 2015b) have looked at training vs. competition loading in any detail. In these studies, comparison of pre-tour and on-tour training loads showed significant increase in tennis volume whilst on-tour. The higher the match and tennis training loads were on-tour, the greater decrements seen in linear speed (Effect size (ES):0.50-0.70) and aerobic power (ES>0.80). Positively, higher match loads typically mean the player is winning more matches. Consequently, the focus of their physical training is shifted to physical preparation alone, often resulting in insufficient exposure to other types of maintenance training needed to maintain pre-tour levels of fitness. Further research is required to know whether the detraining effects occurring are significant enough to impact on tennis performance or on the athlete’s long-term development. Additionally, strength testing was restricted in the two studies by Murphy et al. (2014), Murphy et al. (2015b) and therefore how this is affected by total training loads during tournaments was not accounted for, nor has it been investigated in other tennis research. Nonetheless, this provides some information and insight to guide a players on-tour and post-tour training based on what is known about the regression observed in these studies. Furthermore, the noticeable increase in volume of tennis from training to competition found in these studies, highlights another area of consideration in the periodisation and loading of a junior tennis players training programme. Repeated failure to match competition demands in training may leave players underprepared and therefore at greater risk of injury and underperformance (Murphy et al., 2015a, Murphy et al., 2015b, Murphy et al., 2014).

3.5 Strength and Conditioning Intervention Research on Tennis players

In the last 10-15 years several studies have analysed the impact of different types of S&C methods on the physical and tennis performance of junior players (Table 3.3).

Table 3.3 Summary of all S&C intervention studies conducted in junior tennis players

Type of training intervention	Focus	Author
Neuromuscular training/ Multi-focus programmes	Improving neuromuscular indices in competitive tennis players to reduce injury risk	(Barber-Westin et al., 2010)
	Effects of combing knee ligament injury prevention programme with other exercises to improve athletic performance indicators	(Barber-Westin et al., 2016)
	Effects of combing neuromuscular training within tennis session (before or after) on fitness components of prepubertal players	(Fernandez-Fernandez et al., 2018)
	Effects of combined explosive strength and repeated sprint training on performance in young elite players during competitive season	(Fernandez-Fernandez et al., 2014a)
Resistance training	Comparison of the effects of two different resistance training methods on serve velocity	(Behringer et al., 2013)
	Investigation into effects of short-term strength programme on tennis performance in youth tennis players	(Fernandez-Fernandez et al., 2013)
	Effect of short-term strength programme not leading to failure in young tennis players	(Sarabia et al., 2015)
	Compare effects of 8-week functional training vs traditional training on athletic performance and functional movement in prepubertal players	(Yildiz et al., 2019)
Speed, agility and plyometric training	Investigate the effects of a 6-week resisted sprint training vs conventional unresisted training on physical performance	(Moya-Ramon et al., 2020)
	Analyze the effects of an 8-week plyometric programme combined with regular tennis training in young tennis players	(Fernandez-Fernandez et al., 2015a)
	The acute impact of medicine ball throws on serve velocity and precision during serve training	(Ferrauti and Bastiaens, 2007)
Endurance training	Investigate effects of on-court vs off-court interval training on tennis skill performance and fatigue tolerance	(Srihirun et al., 2014)
	Examination of effects of 6-week of high-intensity sprint interval training vs 6-week on-court tennis training on psychophysiological and performance responses at technical scores	(Kilit and Arslan, 2019)

As previously discussed, for most players, school and a heavy tennis schedule and long competitive season leaves limited time for physical training. Subsequently, the most recent research into this topic has advocated using testing results to create an individual profile highlighting strengths and weaknesses (Ulbricht et al., 2013). This allows for more efficient and effective programme design, utilising the available time to focus training on the area the individual needs most improvement (Fernandez-Fernandez et al., 2014b, Ulbricht et al., 2015a, Ulbricht et al., 2015b). Additionally, it is recommended for tennis coaches and strength and conditioning coaches alike, that understanding the physiological characteristics and loads of on-court drills enables a more integrated approach to both skill development and conditioning (Gomes et al., 2015, Murphy et al., 2015a, Murphy et al., 2013). This information allows specific physical components to be targeted within tennis sessions to optimise training time without adding volume to an already busy schedule or sacrificing skill (tactical or technical) development. Although limited, the research discussed in the next section sought to determine the most effective short term training strategies to maximise performance enhancement within these limited training windows in adolescent populations.

3.6 Research in Youth players

3.6.1 Multi-focus programmes

Three previous studies have investigated the effects of neuromuscular training programmes. In regards to these studies, the term "neuromuscular training" refers to programmes that train different aspects of fitness concurrently, including both general (fundamental movement skills) and specific S&C activities targeted towards motor control deficits (Fernandez-Fernandez et al., 2018). The objectives of these programmes aim to improve fitness and health while reducing risk of injury (Barber-Westin et al., 2016). While their intended outcomes and methodology varied, there was some crossover in the programme content (Barber-Westin et al., 2016, Barber-Westin et al., 2010, Fernandez-Fernandez et al., 2014a, Fernandez-Fernandez et al., 2018) (See Table 3.4). Neuromuscular training is designed to enhance health and skill-related aspects of physical fitness through inclusion of general (fundamental movements) and specific (targeting deficits in motor control) S&C activities (Myer et al., 2005, Fernandez-Fernandez et al., 2018). This type of training has been shown to effective in the prevention of injuries and improving fitness of youth athletes (Myer et al., 2011). Although focused on injury prevention, the studies by Barber-Westin et al., (2010), (2016) theorised that enhancement in the neuromuscular indices used as outcome measures in both studies would subsequently reduce injury risk and improve performance. Moderate to large effects were observed following the interventions (Table 3.4), leading the authors to conclude that participation in a comprehensive, but simple (low-cost, low equipment requirements) programme like this is an effective way for junior tennis players to train (Barber-Westin et al., 2010). However, given that the programme consisted of over 40 different exercises and stretches, it is difficult to ascertain if this was the effect of the training programme as a whole or influenced more strongly by one type of training.

More recently, the timing of a NMT programme combining plyometric exercises with acceleration/deceleration/change of direction drills has been examined (Fernandez-Fernandez et al., 2018). In this study the cohort was divided into two groups to investigate whether the effects of a similar programme would be influenced by when it took place either immediately before or after tennis training. Between-group comparisons showed markedly greater positive effects in the before training group in all tested variables (Table 3.4) whereas the after training group saw trivial or negative effects (Fernandez-Fernandez et al., 2018). The improvements in the before-training group were lower than in the previous studies discussed which additionally both included strength training exercises (Barber-Westin et al., 2010), however the authors noted that amongst other limitations, improvements seen may be related to the substantially lower training volume in their study (Fernandez-Fernandez et al., 2018).

Table 3.4 Summary of S&C Multi-focus intervention studies in junior tennis players

Author	Subjects	Control group Y/N	Type of intervention	Duration	Frequency	Outcome measures	Significant results and effect sizes
(Barber-Westin et al., 2010)	n=15 (5 males 10 females) Age= 13.0 ± 1.5 years	No	Neuromuscular training: Warm up, plyometric and jump training, strength training and speed, agility & tennis drills	6-weeks	3 x 90 minutes per week	Hopping, Abdominal endurance, suicide tests, speed & agility tests	Baseline forehand agility (ES=1.04) Baseline backhand agility (ES=1.13) Service line test (ES=1.84) 1-court suicide (ES=3.04) 2-court suicide (ES=0.78) Abdominal endurance test (ES=0.54 right, 0.50 left)
(Barber-Westin et al., 2016)	n=42 (31 females,11 males) Age 14 ± 2 years	No	Neuromuscular training: Warm up, plyometric and jump training, strength training and speed, agility & tennis drills	6-weeks	3 x 90 minutes per week	Hopping, Abdominal endurance, 1-court suicide tests, speed & agility tests	Baseline forehand agility (ES=0.77) Baseline backhand agility (ES=0.88) Service line test (ES=0.82) 1-court suicide (ES=1.70) Abdominal endurance (ES=0.94) Single leg hop (ES=0.53 right, 0.33 left) Single leg triple crossover (ES=0.46 right, 0.43 left)
(Fernandez-Fernandez et al., 2018)	n=16 (elite male players) Age: 12.9 ± 0.4 years	No 2 groups: Before tennis training (n=8) & after tennis (n=8)	Neuromuscular training: Plyometric training with acceleration, deceleration and COD drills	5-weeks	2 x 30minutes per week	20m sprint (5&10m splits) Modified 5-0-5 CMJ Overhead Medicine Ball Throw test Serve Velocity	"Before tennis training" group 5m (d=0.52),10m (d=0.32),20m (d=1.08) 5-0-5 (d=0.22) CMJ (d=0.29) Medicine Ball Throw (d=0.51) Serve Velocity (d=0.32)
(Fernandez-Fernandez et al., 2014a)	n=8 (Elite male) Age: 16.9 ± 0.5 years	Yes n=8	Combined: Repeated sprint and explosive training	8-weeks	2 x per week	10m & 30m sprint Repeated sprint ability CMJ Maximal Graded Aerobic Test	10m sprint (ES=0.74) CMJ (ES= -0.27) Repeated sprint ability (best and mean) (ES= 0.65 and 0.78)

All three studies achieved positive results across multiple measures of performance or neuromuscular indices correlated to injury risk (Barber-Westin et al., 2016, Barber-Westin et al., 2010, Fernandez-Fernandez et al., 2018) However, they are not without limitations. The studies all took place during a training phase or “off-season” when there is at least a 6-8-week block of time available., While overall neuromuscular training programmes appear to both a cost-effective and ecologically valid in improving physical ability of young tennis players, the latter of the three studies indicates that the sequencing of sessions may also be critical during the training block (Fernandez-Fernandez et al., 2018) . The most recent study also showing that a shorter 30-minute protocol can also produce significant results, therefore offering a more time-effective protocol than the previous studies (Fernandez-Fernandez et al., 2018). These findings provide valid reason to further substantiate this theory through additional research.

An earlier study by Fernandez-Fernandez et al. (2014a) examined the effects of focusing on two specific types of training concurrently. In this instance looking at they investigated the effect of a combination of explosive strength and repeated sprint training programme during the competitive season on physical performance. Significant improvement was seen in the training group performance in 10m, countermovement jumps and repeated sprint ability times post intervention (see Table 3.4), indicating positive neuromuscular improvements. Despite better sprint times in the repeated sprint ability test, the lack of changes in percentage decrement in the repeated sprint ability test and aerobic fitness was suggestive that this type of training only elicited enhancement of anaerobic performance (Fernandez-Fernandez et al., 2014a). The authors noted that combined training may not be as effective as specific component training alone if working towards the individual needs of an athlete, as reported in other sports (Reilly et al., 2009, Young et al., 2001). However, it could be a valuable way of targeting multiple but specific determinants of tennis performance in group sessions and for players limited on training time, adapting focus based on the stage of maturation, gender or playing level (Fernandez-Fernandez et al., 2014a). Given the relatively small and homogenous sample used, further research is needed to be able to apply these conclusions to wider populations.

3.6.2 Strength training interventions

Strength training (also referred to as resistance training) for youth athletes is very well substantiated by evidence of its numerous benefits on health, wellbeing and performance (Lloyd 2012). In regards to performance, research has demonstrated this type of training can elicit improvements in muscular strength, power production, running and change of direction speed and general motor performance (Behringer et al., 2010, Faigenbaum and Myer, 2010, Chaabene et al., 2020).To the authors knowledge from the literature analysed in this thesis, the impact of strength training in junior tennis players has only been examined in males (Behringer et al., 2013, Fernandez-Fernandez et al., 2013, Sarabia et al., 2015). Three studies had similar aged adolescent players (14-16 years old) and one examined pre-pubertal players (8-10 years old). All four had comparable sample sizes (20-33) but utilized different methods and experimental designs as described in Table 3.4. The serve is often considered the most important shot and therefore continual development of velocity and accuracy is an essential part of training (Kovacs and Ellenbecker, 2011b, Hayes et al., 2018, Söğüt, 2017). Consequently improving serve velocity was the main objective of two of the studies (Behringer et al., 2013, Fernandez-Fernandez et al., 2013) and both elicited significant improvement despite distinctly different methods (see Table 3.5). The enhancement in serve velocity found by Behringer et al. (2013) appeared independent of strength improvements in which both resistance training groups (machine-based and plyometric) made equal progress compared to controls. In line with current opinion on specificity, it was acknowledged strength is only one aspect of skill performance, and a lack of velocity and specificity in the machine-based programme led to a lack of transfer to serve performance (Behringer et al., 2013). Meanwhile, shoulder range of motion for both controls and training group in the study by Fernandez-Fernandez et al. (2013) showed significant improvement following the supervised stretching routine both groups followed. However, only the resistance training group showed significant change in serve velocity following an intervention using considerably lighter loading methods (elastic bands, core strength exercises and medicine balls) but like Behringer et al. (2013) also involved upper body plyometric exercises (medicine ball throws) (Fernandez-Fernandez et al., 2013). The authors concluded that this protocol was an effective way of improving tennis performance and reducing injury risk (via improvement in rotational range of motion at the shoulder) (Fernandez-Fernandez et al., 2013). Due to the variance in duration, frequency and methodology of the two protocols it is difficult to pinpoint which element contributed most to improvement in serve velocity. However, this is the first evidence that resistance training at this age can impact on serve performance. As neither study assessed fitness parameters outside the scope of their study, further research is needed to understand the impact on overall tennis performance via progress in other physical areas.

Lastly, Sarabia et al. (2015) focused on investigating the effects of a short protocol that could improve strength without substantially increasing total demands, but serve velocity was not an outcome measure. Sessions in the main programme were <30 minutes duration and focused on maintenance of mechanical power throughout all repetitions and sets of 2 main exercises: bench press and parallel half squat. Post-intervention, moderate to large effect sizes were observed in multiple lower body strength and endurance measures (see Table 3.5) in comparison to controls. Despite minimal upper body strength improvements, upper body power (medicine ball side throw) did see significant change, which the authors related to enhancement in motor coordination and segmental synchronisation as previously noted in youth strength training

(Behringer et al., 2010, Faigenbaum and Myer, 2010). Returning to the issue of limited training time, the authors highlighted the ecological validity of a strength programme that requires less time and allows quicker recovery than training to failure. Additionally, reducing the risk of overuse injury linked to participating in high volume and frequency of specific training when combined with other activity (Kibler and Safran, 2005).

Table 3.5 Summary of resistance training interventions; Protocol characteristics, outcome measures and significant results

Author	Subjects	Experimental design	Control group Y/N	Duration	Frequency	Outcome measures	Significant results and effect sizes
(Behringer et al., 2013)	n=33 male players Age: 15.03 ± 1.64 years	Machine-based resistance training group vs Plyometric training group vs control group	Yes n=13 machine-based group n=10 plyometric group n=10 controls	8-weeks	2 x per week	10RM Strength testing – Leg press, Chest press, pull down machine & abdominal press. Serve velocity & precision	Significant strength gains (p<0.05) occurred in both training groups. Plyometric training group saw significant improvement in maximum velocity serve (p<0.05) with 3.78% improvement.
(Fernandez-Fernandez et al., 2013)	n=30 Nationally ranked male player Age:14.2 ± 0.5 years	Resistance training group vs controls: Training group; core strength, elastic bands, medicine ball Both: Supervised stretching routine	Yes n=15 training group n=15 control group	6-weeks	3 x 60–70-minute sessions per week	Maturity Serve velocity & accuracy. Shoulder internal/external rotation	Serve velocity in training group (ES=0.41) Shoulder internal & external rotation in both groups (Training group ES=0.50, Control group ES=0.36)

Table 3.5 (continued) Summary of resistance training interventions; Protocol characteristics, outcome measures and significant results

Author	Subjects	Experimental design	Control group Y/N	Duration	Frequency	Outcome measures	Significant results and effect sizes
(Sarabia et al., 2015)	n=20 (Competitive male player Age: 15.0 ± 1.0 years	Training group vs controls: Short protocol <30mins using smith machine-based resistance, bodyweight and medicine ball plyometrics	Yes n=11 training group n=9 control group	11-weeks:4-weeks anatomical adaptation, 6-weeks for main programme 2-week taper	2 x 30min per week	Squat jumps CMJ 1RM Supine bench press & Parallel half squat Parallel half-squat power output test Parallel half squat endurance test Medicine ball throw Forehand & backhand Salivary cortisol Profile of Moods questionnaire	In training group only: Squat jump (η^2 =0.54) CMJ (η^2=0.34) Parallel half squat endurance test: Mean (η^2 =0.58) and peak power output (η^2 =0.60) &Number of repetitions (η^2 =0.73) Parallel half squat power output test: Mean force (η^2 =0.51), power (η^2 =0.42) and velocity (η^2 =0.36) Medicine ball throw (dominant side) (η^2=0.49)
(Yildiz et al., 2019)	n=28 male players Age:9.6 ± 0.7 years	Functional training (multi-joint, multi planar exercises) vs Traditional training (single joint, single plane exercises) vs controls	Yes 3 groups: Functional training group n=10 Traditional training group n=10 Control group n=8	8-weeks	3 x 60mins per week	FMS™ Balance (dynamic & static) CMJ 10m sprint Sit & reach T-test	Functional training group: Significant improvement in measurements ($p<0.001$ Traditional training group: Significant decrement in FMS™ ($p<0.001$) Dynamic balance (both sides) increased ($p<0.001$) **no effect sizes were reported*

Most recently, the introduction of resistance training to prepubertal tennis players (males aged 8-10 years) has been explored. "Functional training' describes programmes based around "target movements" as opposed to specific muscles groups or actions, believed to have better transfer to sport performance (Yildiz et al., 2019). The results of this study agreed with this suggestion, with significant improvement seen in all areas (movement screening and physical performance measures) observed in the functional training group ($p < 0.001$), whereas the traditional training only saw notable change in dynamic balance and decrement in FMS screening scores (Yildiz et al., 2019). Large ES were seen in all measures (ES=1.5-3.8), which is a positive finding for S&C practitioners working with young tennis players. As it is suggestive that FMS and strength can be developed concurrently for those starting lacking movement competency and/or with poor time availability.

3.6.3 Speed, Agility and Plyometric training interventions

These training modalities all focus on the different physical components which facilitate effective and efficient movement, leading to enhanced movement velocities and explosivity (Oliver et al., 2013). This type of training is typically inclusive of exercises focused on technique, tendon stiffness and power, along with multiple other secondary components known to influence performance such as coordination, balance and perception and reactive abilities (Oliver et al., 2013, Cooke et al., 2011). To date, three studies have examined the impact of training interventions involving speed, agility or plyometric training. Each study had a different focus and methodological approach making them difficult to compare to one another. However, they have created an initial foundation of information on the application of this type of training in junior tennis players, The impact of a biweekly plyometric protocol on markers of physical fitness and serve performance on 12–13-year-old males was examined by Fernandez-Fernandez et al. (2015a). The protocol consisted of both upper and lower body plyometrics as a substitute for 30-60 minutes usually devoted to technical training (Fernandez-Fernandez et al., 2015a).The training group were found to achieve significant percentage improvements in all parameters measured (3.1-10.1%), with small to moderate effect sizes (ES = 0.4-1.3) (Table 3.6). The control group showed no significant change in the parameters measured and the authors concluded that the results reinforced the need for specific power training to enhance explosive movements in tennis (Fernandez-Fernandez et al., 2015a). This training was a replacement for up to 3hrs of tennis training per week, and whether these physical improvements were at the detriment of overall tennis performance due to the time lost in technical training, is unknown as this was not measured. In contrast Ferrauti and Bastiaens (2007) found that upper body plyometrics does not have an immediate or post-activation potentiation effect on serve performance of players of a similar age. A crossover design comparing immediate effect of weighted ball throw intervention within serve training sessions was investigated. There was no evidence seen of post activation potentiation but rather an acute decrease in serve velocity after the heavy throw (600g) intervention. It was concluded that the use of weighted throws during serve training was non-beneficial in this age group and level of player (Ferrauti and Bastiaens, 2007). However, what the impact of this type of training if repeated on a weekly basis for a longer duration was not explored, so although both using medicine ball throws as a form of upper body plyometric training, these two studies are not comparable. It may be assumed plyometric training as with other forms of training requires a minimum dose to create adaptation. Therefore, it may be most beneficial in the form of a longer intervention, which if this is the case then finding a balance between tennis and physical training or a more integrative approach may be of upmost importance.

Only one study has examined the effect of sprint training intervention on junior tennis players (Moya-Ramon et al., 2020).This study compared the effects of two different types of sprint training over 6-weeks. One group utilised resisted sprint training methods (weighted vests and elastic cords) (n =10) and the other group used conventional sprint training techniques (n =10). I No measures of tennis performance were assessed, and small-moderate effects seen in all physical parameters measured (sprint, jumping, change of direction pivoting and percentage decrement in repeated sprint ability test) following both training regimens (Table 3.6). The resisted sprint training group improved more than conventional training group in standing long jump and 5m, giving support to this type of sprint training. However, due a lack of control group or any other studies looking at similar interventions in comparable tennis cohorts, evidence-based practice is still reliant on information drawn from sprint training interventions in other sports. This highlights that this is clearly another under researched area in junior tennis.

Table 3.6 Summary of speed, agility and plyometric interventions; Protocol characteristics, outcome measures and significant results

Author	Subjects	Experimental design	Control group Y/N	Duration	Frequency	Outcome measures	Significant results and effect sizes
(Fernandez-Fernandez et al., 2015a)	n=60 Male players 12.5 ± 0.3 years	Training group vs controls	Yes	8-weeks	30-60mins twice a week in substitution of tennis training	CMJ, Standing long jump 5,10 & 20m sprints, Modified 505 Overhead medicine ball Serve velocity & accuracy	CMJ (ES=0.46) Standing long jump (ES=-1.08) 5,10 and 20m sprint (ES=0.97, 0.87 and 0.83) Modified 505 (ES=0.58) Overhead medicine ball test (ES=-0.52) Serve velocity (ES=-0.79) Accuracy (ES=-0.46) No significant changes in control group
(Ferrauti and Bastiaens, 2007)	n=13 Male and female players 12.3 ±0.8 years	3 interventions:200g ball throws, 600g ball throws or nil throws between sets of serves Players completed 4x6 serves. During rest players performed 6/4/2 maximal throws or nil	No Comparison made to their own performance in each intervention	One-off interventions assessed on three different days	3 days	Serve velocity & precision “Service touch” – 11-point rating scale	Serve velocity significant decrease in response to 600g ball intervention (effect size d=0.26) in compared to no intervention
(Moya-Ramon et al., 2020)	n=20 Male players 16.5 ± 0.3 years	Comparison of resisted sprint training method to traditional sprint training methods	No	6-weeks	2 x per week	5,10&20m sprints Standing long jump Repeated sprint ability Vertical jump	Both groups made significant change in all measured parameters (ES=0.16-0.69) Resisted sprint training group improvements in SLJ (ES ± 90% CI = 0.31 ± 0.34) ,5m sprint time (ES ± 90% CI = 0.29 ± 0.43) were ***possibly*** larger than in the traditional methods group

3.6.4 Endurance training interventions

This type of training typically refers to the development of aerobic capacity, most often measured by assessment of VO^2 max (Srihirun et al., 2014). High intensity interval training (HIIT) is most commonly used in tennis, as it is thought to be more specific to the intermittent nature of tennis and has been shown to be an effective method of improving VO^2 max in other sports (Impellizzeri et al., 2006, Sperlich et al., 2011). Two very similar studies into the effects of different types of endurance training have been investigated in adolescent males (Kilit and Arslan, 2019, Srihirun et al., 2014). Each study compared two different methods of interval training to establish how each method influenced skilled tennis performance and VO2-max (Table 3.7). The study by Kilit and Arslan (2019) used slightly younger players (aged 13.8 ± 0.4 years) and also included measures of components of physical fitness. The experimental design in both cases was a direct comparison of the effects of specific on court tennis training drills following strict work to rest ratios against high intensity interval training which was performed on the treadmill (Srihirun et al., 2014) or 400m running track (Kilit and Arslan, 2019). The results indicated that although both types of training elicited significant improvement in VO2-max in each study, the on-court tennis training groups saw much larger effects on technical performance in their respective skill tests (Kilit and Arslan, 2019, Srihirun et al., 2014). Additional findings demonstrated the protocol used by Kilit and Arslan (2019) produced greater effects on agility performance.

The results of both studies are in agreement with research in other sports and the training principle of specificity, indicating that adaptation occurs in direct relation to the specifics of the training programme (Reilly et al., 2009, Parsonage et al., 2014, Young et al., 2001, Fernandez-Fernandez et al., 2015b, Fernandez-Fernandez et al., 2012). Although further research is needed, the level of agreement on this topic is important for the tennis community as it provides evidence that aerobic capacity can be developed within tennis sessions whilst working on skill development, without adding load to the already busy schedule of junior players.

Table 3.7 Summary of endurance training interventions: Protocol characteristics, outcome measures and significant results

Author	Subjects	Experimental design	Control group Y/N	Duration	Frequency	Outcome measures	Significant results and effect sizes
(Srihirun et al., 2014)	n=20 Male players Age:16.6 ± 0.6 years	Two groups: On-court interval training (specific hitting and footwork drills) (n=10) Off-court interval training (treadmill-based intervals)	No	8-weeks	3 x per week	VO2 max Loughborough Intermittent Tennis test (LITT) (groundstroke accuracy, consistency & error scores Time to volitional fatigue on LITT & Treadmill test	Both groups: Significant improvement in VO2 max ($p < 0.05$). On-court: 10.68% Off-court: 6.66% On-court group only: $p < 0.05$ groundstroke accuracy score and mean time to fatigue
(Kilit and Arslan, 2019)	n=29 Male tennis players Age: 13.8 ± 0.4 years	2 groups: High-intensity interval training group (HIIT) and on-court tennis training (OTT)	No	6-weeks	2-3 sessions per week (2x2pw, 4x3pw)	Hit & turn tennis test (VO2 max) 400m 20m sprint (5m & 10m splits) International Tennis number test (technical) T- drill agility CMJ Squat Jump Drop jump	Both groups saw significant improvement in all measures ($p < 0.05$). Very similar large effect sizes observed in both groups in jumping and 5,10&20m sprints (d=0.4-1.10). VO2 max also very similar (OTT: d=1.36 vs 1.55 in HIIT) The OTT group saw larger effects in T-drill agility (d=0.88 vs 0.56 in HIIT) and technical score (d=0.77 vs 0.32) The HITT group saw larger effects in 400m (d=1.32 vs 0.60 in OTT)

3.7 Summary

It is evident from the existing literature that the development of junior tennis player present unique challenges and complexities that make it difficult to follow conventional methods of periodisation for physical training. Multiple sources advocate at least 15-20 hours a week is devoted to tennis training, this skill development dominated programme means that S&C coaches need to optimise their time spent focused on the players' physical development (Reid et al., 2003, Ochi and Campbell, 2009). As good levels of all physical abilities are needed for tennis performance, current recommendations suggest that physical programmes should be centred on the individual's biggest weaknesses and matched to their stage of maturation (Ulbricht et al., 2013, Unierzyski, 2002). Limited data on the frequency and volumes of training is available, however this information suggests that elite juniors currently participate in 20-25 hours of total training volumes at U16 level (Fett et al., 2015, Fett et al., 2017). This is likely to have been reached that point by gradual progression from the age of 12, at which point most elite players have already specialised (Ochi and Campbell, 2009). Further research is needed to understand the part that training and competition characteristics during adolescence plays in the career of a player. However, based on the clear difference in the training volumes of elite players in comparison to sub elite and the noticeable difference in physical ability (Fett et al., 2017, Ulbricht et al., 2015a), there seems sufficient evidence to emphasise the importance of S&C within the youth programmes.

In terms of enabling evidence-base practice as to the type of interventions used with this population, 13 youth intervention studies were available to review. Of those 13 studies, 6 focused on U14 players, 4 at U16, 2 at U18, 1 at U10 and 1 covered all age groups between 11-16 years of age. These studies were distributed across 4 main fitness components, creating what can only be described as only a foundation of information in each area, requiring significantly more research before it can be more widely applied. Additionally, 10 of the 13 studies used all male participants (3 studies using mixed cohorts), leaving a large gap when it comes to understanding the impact of these protocols on female athletes of the same chronological age. Given what is known about differences between genders in regards to rate of maturation (Lloyd and Oliver, 2012), as well as difference in tennis game styles and demands, (Fernandez-Fernandez et al., 2009), it seems prudent to extend this research to female players.

Chapter 4 – The physical fitness, growth and anthropometric characteristics of New Zealand Junior Tennis Players and their relationship to Tennis Performance

4.1 Preface

Synthesis of the literature reviewed in Chapter 2 showed limited studies have explored the link between maturation, physical and anthropometric characteristics of junior tennis players with performance (Myburgh et al., 2016b, Ulbricht et al., 2015b, Fernandez-Fernandez et al., 2014b). Overall their findings have indicated that a number of physical components contribute to tennis performance (Roetert et al., 1996, Fernandez-Fernandez et al., 2014b). However, more recent research indicates a growing consensus as to which specific components influence performance particular genders and or age-groups (Fett et al., 2018, Kramer et al., 2017a). One of the overarching aims of this thesis was to gain understanding on how S&C influences athletic development of players aged 10-14 years old and subsequently how this influences tennis performance in this age group. To do this accurately for the population in question, first it must be ascertained whether NZ players present the same trends and traits in physical and anthropometric characteristics as observed in other international cohorts. This will contribute to a better understanding in the following chapters, on how current S&C practice may be influencing athletic development and the usefulness of future introduction of S&C interventions.

4.2 Introduction

In order to develop a successful long-term athlete development plan for any youth athlete, a sound understanding of the physical requirements of the sport in question is required (Kovacs, 2009, Kovacs, 2006, Roetert et al., 2009a, Roetert et al., 2009b). Extensive examination of the physical and physiological demands of tennis means that this information is readily available, and it is generally accepted that to compete at elite level, players require high levels of physical fitness (Roetert et al., 2009a, Roetert et al., 2009b, Ellenbecker et al., 2009, Maquirriain and Baglione, 2015). The sport is characterised by large demand for rapid movement across short distances (mean 3m) with multiple change of directions (up to 1000 per match) accompanied by 300-500 high intensity efforts producing large forces to execute fast but accurate shots (Fernandez-Fernandez et al., 2014a, Kovacs, 2006, Kovacs, 2009, Cooke et al., 2011). In early adolescence speed and agility has most frequently been found to be a predictive factor of performance and having the ability to differentiate between playing levels at U12 (Roetert, 1992, Roetert et al., 1996, Filipčič et al., 2004, Kramer et al., 2021, Kramer et al., 2017b, Kramer et al., 2016b, Girard and Millet, 2009, Unierzyski, 2002). Whereas the findings from studies in U14+, suggest the role of upper body power and strength related characteristics have a greater influence on determining junior tennis performance (Ulbricht et al., 2015a, Kramer et al., 2016a, Fett et al., 2017, Girard and Millet, 2009, Ulbricht et al., 2015b).

Chapter 2 also drew attention to the presence of relative age effect within elite junior tennis populations, with overrepresentation born in the first half of the year (Agricola et al., 2013). Additionally, relationships between anthropometric measures and performance, particularly height, consistently show a positive correlation to serve performance (Bonato et al., 2015, Vaverka and Cernosek, 2013, Hayes et al., 2018) and performance physical parameters (Myburgh et al., 2016b, Myburgh et al., 2016a, Fett et al., 2018). This is reflective of how the anthropometric advantages afforded to those with advanced maturation can impact tennis performance and a point of consideration for selectors and coaches alike. Therefore, the aim of this study was to characterise the physical, growth, and anthropometric characteristics of youth NZ tennis players and to explore relationships with tennis performance.

4.3 Methods

4.3.1 Experimental Approach to the Problem

Due to the geographical spread of players throughout NZ, the National Championships was identified as an event which would draw the greatest number of players from each region. This event also provided an opportunity for those who failed to meet the standard of the qualifying draw a chance to compete in a third-tier tournament at the same venue and provided an opportunity to compare elite players to sub-elite players within these age groups at the same time. Due to the proximity of the testing session to competition, only tests that did not elicit significant fatigue or muscle soreness were selected. These also aligned with previous research to allow comparison and to ensure validity (Myburgh et al., 2016b, Ulbricht et al., 2015a, Ulbricht et al., 2013).

4.3.2 Subjects

Participants (n=108, 56 males and 52 females) consisted of players competing in age-group NZ National Championships in 2017. In addition, a third-grade tournament in both U14 and U12 age groups was run concurrently for those not making the ranking cut for the National main or qualifying draw. This tournament was open to the top 96 nationally ranked players in each age group. Descriptive statistics of all subjects are detailed in Table 4.1 below. Subjects participated on a voluntary basis during the 2 days before each respective event commenced, self-selecting which testing session they attended. All testing sessions were run in the morning on an indoor hard-court in small groups of 6–8, led by the same primary researcher.

Table 4.1 Descriptive statistics of all subjects

	U12 Girls (n=29)	U12 Boys (n=32)	U14 Girls (n=24)	U14 Boys (n=25)
Age (years)	11.7 ± 0.8	11.8 ± 0.9	13.9 ± 0.7	13.9 ± 0.6
Height (cm)	149.86 ± 8.3	152.62 ± 7.2	164.03 ± 7.4	165.6 ± 8.3
Sitting Height (cm)	78.05 ± 3.8	78.36 ± 3.6	84.82± 4.5	85.9 ± 5.1
Weight (kg)	43.85± 9.7	41.27± 7.1	54.25± 9.1	55. ± 9.2

4.3.3 Procedures

Before commencing testing, all subjects were fully informed about the purpose, procedures and possible risks of the study (See Appendix C). As subjects were all under the age of 16 years old, written assent was gained in addition to informed written consent of the parent/guardian (See Appendix D). The Auckland University of Technology Ethics Committee approved this study (AUTEC reference:16/131). Participants provided their personal details including their name and date of birth to the primary researcher. A standardised 15-minute warm up protocol was then completed, consisting of a cardiovascular section designed to raise heart rate and elevate tissue temperature as well as dynamic stretches, activation exercises and sport specific movement skills (See Fig 4.1). The tests were then completed in the order listed in Table 4.2.

Table 4.2 Order of tests in testing battery

Order	Test
1	Anthropometry – Height, Sitting Height, Weight
2	Sit and Reach – Hamstring flexibility
3	Upper Body Strength - Grip Strength Dominant and Non-Dominant
4	Lower Body Power and Strength – Countermovement jump and Squat Jump
5	Upper Body Power – Overhead Medicine Ball Throw
6	Agility - Forehand and Backhand Agility
7	20m Sprint – 5, 10 and 20m splits
8	Serve Velocity and Accuracy

Performance Preparation

To be done prior to any session Tennis or fitness

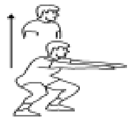
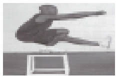
1. CARDIO WARM UP
2.DYNAMIC STRETCHES
3.ACTIVATION

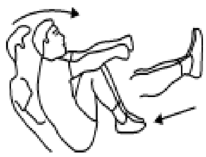
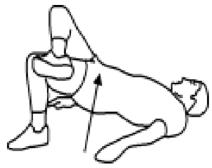
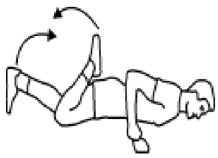
CARDIO WARM UP
5 times around court or 5 min skipping

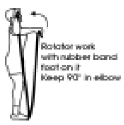
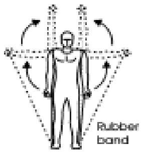
DYNAMIC STRETCH
Ankling (2)
All exercises to be completed forward and backward holding racket
Lunge walk / rotation(0.5)
Hamstring scoop (0.5)
open gate/Gambetta lunge(o.5)
Carioca 2()
3 right two left (2)
high knees with buttkicks (2)
3forward two back ward (2)
Giant circles (0.5)
Forward and back jumps (1)
forward and back hops (1)
Side ways hops (0.5)

4PS

ACTIVATION EXERCISES

1		2		3	
Squat		SL squat		press up rotation	
		 OR 		 OR 	
Reps	Sets	Reps	Sets	Reps	Sets
10	1	5el	1	10	1

4		5		6	
V sit		Glute bridge		Hamsting flick	
					
Reps	Sets	Reps	Sets	Reps	Sets
10	1	5el	1	10	1

external rotation		New I YTVS		
				Once activations completed fast feet starts with sprint forward , laterally and double changes
Reps	Sets	Reps	Sets	
10	1	10	1	

NOTE. If you cannot maintain frontal knee alignment you must either perform smaller slower jumps or do not perform continous/ multiples

Figure 4.1 Standardised warm up protocol

Personal information: Participants first completed their own testing sheet including their name and date of birth before the session in order to later calculate biological and stage of maturation in combination with anthropometry measures described below. Which hand they played with was also recorded to ensure data was recorded on the correct side for each test.

Anthropometry: Testing started with measurements of height, sitting height and weight. Height and sitting height were both assessed using a portable stadiometer (Seca, Hamburg, Germany), with players seated on a 52 cm box to measure trunk length. Weight was measured using a digital scale (Seca 213, Hamburg, Germany). These dimensions were subsequently used to calculate each players biological maturity through prediction of age of PHV using the equation devised by Mirwald et al. (2002). Peak height velocity provides an accurate reference point of maximum growth during adolescence by subtracting chronological age at time of measurement from chronological age at PHV. This enables biological age of maturity to be estimated (Mirwald et al., 2002).

Grip Strength: Handgrip strength was measured using a digital hand dynamometer (Jamar Plus Digital Hand dynamometer, Patterson Medical). The player started with their dominant arm above their head and was asked to complete a maximal voluntary contraction whilst bringing their arm through the sagittal plane for approximately 3 seconds to finish with their arm by their side Myburgh et al. (2016b). They then repeated this on the non-dominant arm, completed the process a second time on both sides with the best score for each arm being used for analysis. Although this method is not gold standard for measuring upper body strength, it was most time effective for this untrained cohort and caused minimal fatigue. It has repeatedly shown strong correlations to absolute strength, endurance and upper limb function (Trosclair et al., 2011, Richards and Palmiter-Thomas, 2017, Isen et al., 2014).

Lower Body Power and Strength: First, Countermovement jumps (CMJ) were performed on a contact mat (Swift Performance, Australia). Arm swing was permitted, and players were given three attempts with at least 2 minutes recovery between each attempt. The highest jump height (estimated from flight time) recorded to the nearest 0.1 cm was recorded for further analysis. Following the same protocol, the Squat jump (SJ) was performed with players instructed to squat and hold position for 2 seconds before jumping and to keep their hands on hips throughout. For both jumps, players were permitted a single practice attempt for familiarisation purposes.

Upper Body Power: A tennis specific overhead medicine ball throw was used to assess upper body power, as previously described by various tennis federations including the Lawn Tennis Association (LTA – British Tennis), German Tennis Federation and the USTA (Myburgh et al., 2016b, Roetert et al., 1996, Ulbricht et al., 2015a). The protocol selected for this study has previously been described by (Myburgh et al., 2016b) Using a 1 kg medicine ball, the overhead throw (OHMB) was initiated from a serve stance with players taking the ball behind their head, instructed to throw the ball with two hands using their normal service action. Players had three attempts at each throw with passive rest in between attempts, throws were measured to the nearest 5 cm with the furthest distance used for analysis.

Change of direction: Change of direction speed was assessed using the Forehand Agility (FAT) and Backhand Agility test (BAT) as described by Myburgh et al. (2016b). This test is part of performance testing battery used by the LTA in assessment of British Tennis players (Myburgh et al., 2016b). Electronic timing gates (Swift Performance, Australia) placed perpendicular to the centre of the baseline recorded the time it took for players to sprint from the centre of the court to the inside tramline and back on both their forehand and backhand sides. Starting 30 cm from the centre of the baseline in a tennis ready position, players were asked to sprint to touch a cone placed on the intersection of the baseline and singles line with their racquet arm, initiating the movement with a split step. Three attempts were completed with the fastest time recorded to the nearest 0.01 s recorded, with 2 minutes passive recovery in between each attempt. This process was completed on both the forehand and backhand sides.

Speed: A 20 m sprint with splits at 5 m, 10 m and 20 m was selected to measure speed using electronic timing gates (Swift Performance, Australia). Players self-started using a split step from a tennis ready position 30 cm behind the first timing gate, as described by Myburgh (2016b). Starting in this position was included to improve specificity of the test in line with tennis movement patterns to the on-court linear movement of tennis players and therefore increasing specificity. The fastest trial of three attempts was recorded, measured to the nearest 0.01 s.

Tennis performance: Tennis performance was defined by national ranking within age-group (U12 and U14), each category spanning two years and three birth years, in addition the serve performance test was used as a measure of skill execution. The serve performance test has been proven to show high external validity in regards to correlation to tennis functional performance, as it is a multi-segment movement requiring coordination, power production throughout the kinetic chain and correct timing of all muscle activations (Fernandez-Fernandez et al., 2014b). It also has been previously highlighted as the most reliable measure of on court performance and has shown good correlation with junior individual ranking (Fernandez-Fernandez et al., 2014b). The radar gun was set up 6 m behind the server and 3.2 m high, target boxes marked out as depicted in Figure 4.. After a brief warm up the server was asked to hit 8 maximal “T” serves all to the advantage side. The fastest ball velocity recorded was used for analysis, serve accuracy was determined by the total number of points achieved in all serves, (3 points for hitting most accurate target, 2 for the surrounding three boxes, 1 for the correct service box, 0 for outside the box). Each individual testing session was provided with 8 new tennis balls (Wilson, Australian Open) for the purpose of standardisation. Experienced tennis coaches assisted in the assessment of accuracy, watching the ball landing from both a front-on and lateral view of the service box and scoring -1 if the ball landed outside the singles court (Fernandez-Fernandez et al., 2014b).

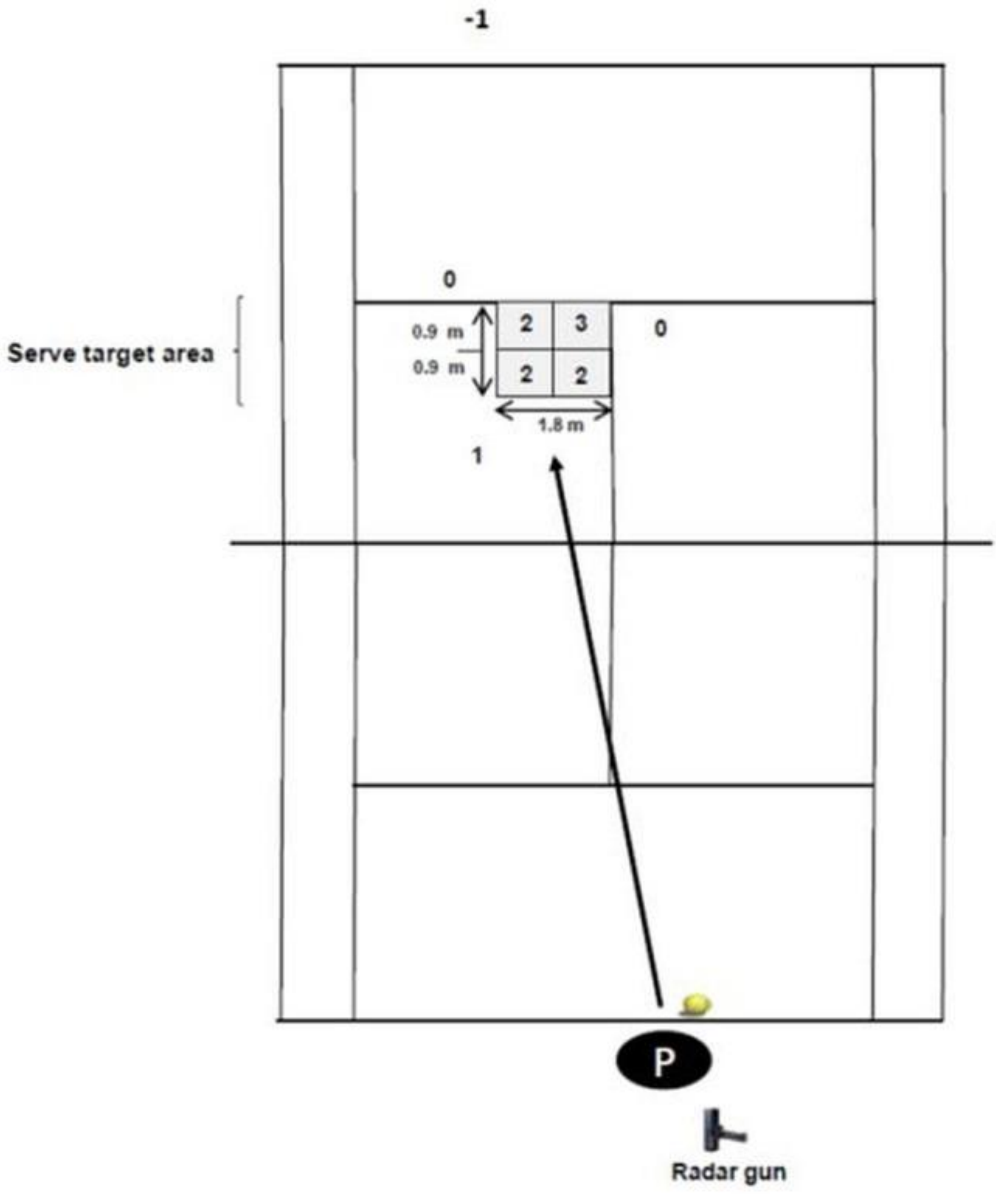


Figure 4.2 Schematic representation of Serve performance test (Fernandez-Fernandez et al.,2014)

Reliability

CV and ICC scores produced from the data of this cohort were used to evaluate reliability of all testing measures and is reported in Table 4.3. These scores are reflective of intra-session CV's and ICCs and were calculated from the participants multiple efforts on the same day. As a result, they might not reflect day-day variation.

Table 4.3 Reliability CV's and ICCs for all fitness and tennis testing measures

Test	CV	Intraclass Correlation	95% Confidence Interval		
			Lower Bound	Upper Bound	P
Grip Strength		0.98	0.95	0.98	<0.001
Countermovement Jump Height	4.6	0.96	0.53	0.98	<0.001
Squat Jump Height	5.9	0.93	0.70	0.97	<0.001
Overhead Medicine Ball Throw	6.2	0.92	0.27	0.97	<0.001
5m	3.6	0.84	0.19	0.94	<0.001
10m	2.0	0.94	0.40	0.98	<0.001
20m	2.3	0.93	0.71	0.98	<0.001
Forehand Agility Test	3.0	0.84	0.36	0.94	<0.001
Backhand Agility Test	2.9	0.87	0.40	0.96	<0.001
Serve Velocity and Accuracy Test	1.8	0.99	0.87	0.99	<0.001

4.4 Statistics

The relative age effect was analysed by categorising players into halves and quarters of the year based on birth date. Frequencies within each gender and age group were then recorded and compared to the mean distribution of birth dates within the general population for those specific birth years.

National ranking was allocated as per the ranking system run by the National Federation, Tennis NZ. Differentiation between playing level was ascertained via a ranking of >16 (elite) and <16 (sub-elite), with players with a ranking of >16 on paper capable of winning at least one match in the main draw of the National Championships (Tier 1).

Data was checked for normality via the Shapiro-Wilk test, and anthropometric and fitness variables were reported as mean or median and standard deviation or interquartile ranges based on the outcome of this test. Given the presence of some variables that were found to be not normally distributed (age, biological age, serve velocity and ranking), Spearman's rankings were used to calculate all correlations. Correlation strength was described as per Cohen (1988), where threshold values were 0.1-0.3 (small), 0.3-0.5 (moderate) and <0.5 (large). An independent-samples t-test was used to compare group means of the different playing levels, the level of significance used was $p<0.05$, with Hedges' g used to calculate effect size of these changes. Effect sizes were described as in accordance with Fritz et al. (2012), with ≥0.2 defined as small, ≥0.5 medium and ≥0.8 large.

4.5 Results

4.5.1 Relationship between maturity and anthropometry measures with physical testing performance

Females

In U12 female players' stronger relationships were found between biological age and anthropometric measures than with chronological age, with large correlation coefficients (height r=0.86, sitting height r=0.75, weight r=0.82) (See Appendix E). Additionally, large correlations were found between biological age and measures of grip strength (dominant r=0.77, non-dominant r=0.82) and overhead medicine ball throw (r=0.65). Significant correlations were found between chronological age and predicted age at peak height velocity and alike variables demonstrated similar trends but to a lesser extent.

In U14 females, chronological age only showed significant correlation to countermovement jump (r=0.50) but did not correlate to anthropometric measures. Predicted age at peak height velocity demonstrated the largest correlation to height (r=-0.79), sitting height (r=-0.80) and weight (r=-0.68). There were large correlations to grip strength (dominant r=-0.59), overhead medicine ball throw (r=-0.53), 5m sprint speed (r=-0.52) and a moderate correlation to countermovement jump (r=0.42). Biological age had similarly large correlations to anthropometric measures to predicted age at peak height velocity and was moderately correlated with grip strength (non-dominant r=0.49) forehand agility (r=-0.48), 5m (r=-0.44) and 20m (r=-0.48).

Males

U12 males presented similar trends to their female counterparts in terms of the relationships of biological age with anthropometric measures and physical testing variables (height r=0.80, sitting height r=0.84, weight r=0.79, grip strength dominant r =0.62, grip strength non dominant r=0.72, overhead medicine ball r=0.51) (See Appendix E).

Correlations of lesser magnitude were observed between chronological age and height (r=0.59) sitting height (r=0.44) and weight (r=0.42) and physical performance measures (grip strength dominant r=0.44, grip strength non dominant r=0.61, overhead medicine ball r=0.42). Predicted age at peak height velocity only presented a significant relationship with age (r=0.67), but no other variables.

Similar trends were observed in U14 males, with the largest correlations observed between biological age with anthropometric measures (height r=0.88, sitting height r=0.90, weight r=0.91). Biological age also had the largest correlations with physical performance variables grip strength (dominant r=0.70, non-dominant r=0.62), overhead medicine ball throw (r=0.60) and 20m sprint (r=-0.49). Less variables were correlated with chronological age in males (Grip strength dominant r=0.54, grip strength non-dominant r=0.46, overhead medicine ball r=0.52). Age at peak height velocity showed similarly large correlations with anthropometric measures (height r=-0.84, sitting height r=-0.93, weight r=-0.79), yet only moderate negative correlations with grip strength (r=-0.49).

Table 4.4 Mean and Median values for age, maturity, anthropometric and physical characteristics of male and female junior players

	Mean ±SD/ Median (25th and 75th)			
	U12 Females	U12 Males	U14 Females	U14 Males
Age (years)	11.7 ± 0.84	11.8 ± 0.92	13.9 ± 0.65	13.9 ± 0.61
Biological Age (years)	-0.24 ± 0.81	-1.99 (-2.3-1.3)	1.68 ± 0.76	0.07 ± 0.85
Age at Peak Height Velocity (years)	12.01± 0.48	13.75 ±0.48	12.3 ± 0.76	13.82 ± 0.68
Grip Strength Dominant (kg)	24.24 ± 5.73	25.01 ± 5.54	28.45 ± 7.33	37.91 ± 9.03
Grip Strength Non-Dominant (kg)	21.15 ± 5.35	20.76 ± 4.99	24.73 ± 8.08	32.34 ± 8.68
Sit and Reach (cm)	28.28 ± 9.54	20.6 ± 5.67	29.46 ± 6.92	23.97 ± 6.34
Countermovement Jump Height (cm)	27.67 ± 4.25	29.52 ± 4.21	28.67 ± 2.64	38.48 ± 36.90
Squat Jump Height (cm)	23.25 ± 4.50	24.70 ± 4.60	24.62 ± 3.17	32.12 ± 3.58
Overhead Medicine Ball Throw Distance (m)	7.46 ± 1.41	7.69 ± 1.23	8.70 ± 1.58	10.42 ± 1.33
Forehand Agility (s)	2.56 ± 0.16	2.50 ± 0.11	2.40 ± 0.16	2.34 ± 0.10
Backhand Agility (s)	2.65 ± 0.20	2.59 ± 0.15	2.53 ± 0.17	2.38 ± 0.08
5m (s)	1.25 ± 0.78	1.18 ± 0.08	1.15 ± 0.05	1.11 ±0.040
10m (s)	2.15± 0.13	2.08 ± 0.11	2.02 ± 0.07	1.92 ± 0.09
20m (s)	3.84± 0.26	3.72 ± 0.20	3.58 ± 0.14	3.38 ± 0.17
Peak Serve Velocity (kmph)	110.09 (101.3 -119.5)	125.08 ± 13.02	122.96 ± 14.81	148.33± 15.68
Mean Serve Velocity (kmph)	102.46 (92.50 – 114.70)	117.31 ± 14.63	117.8 ±15.44	139.40 ± 15.70
Serve Accuracy	6.36 ± 2.70	5.32 ± 2.47	7.5 ± 2.53	7.57 ± 3.94
National Ranking	31.2 (7 – 37.5)	48 (20–94)	39.37 (6.75–77.75)	17.0 (5–82)

*Data which was found to be normally distributed is reported as Mean ± SD, whereas data found to be not normally distributed is reported as Median with 25th and 75th Interquartile ranges

4.5.2 Relationship between anthropometric and physical testing measures with Tennis Performance

The correlations between growth, anthropometry and physical testing measures assessed with tennis performance markers are detailed in Table 4.5.

Maturity and anthropometry

In three of the four age groups chronological age had a moderate to large correlation to National ranking (U12 males r=-0.59, U14 males r=-0.51, U14 females r=-0.41). The exception was U12 females whose only correlation between maturity measures and ranking was sitting height (r=-0.46). Maturation timing in U12 males was also significantly correlated to ranking, with both biological age (r=-0.45) and predicted age at peak height velocity (r=-0.42) showed moderate correlation.

Regarding serve performance, biological age had large correlations to peak speed in three out of the four age groups (U12 males r=0.60, U14 males r=0.77, U12 females r=0.62). The same three groups also showed large correlations to height, sitting height and weight (see Table 4.5). The U14 females were the exception to this with no significant findings in any of these measures., Apart from U12 females, all groups showed a moderate to large correlation to chronological age (U12 males r=0.41, U14 males r=0.56, U14 females r=0.62). The only group to show significant correlation between ranking and serve accuracy was U12 males (r=-0.43).

Physical fitness variables

Forehand agility (r=-0.54) showed the greatest relationship to national ranking amongst U12 females. Moderate correlations to grip strength (dominant) (r=0.40) squat jump (r=0.48) overhead medicine ball (r=0.49), backhand agility (r=0.44) and sprint speed (10m r=0.40, 20m r=0.45) were also found. Similarly, at U14, the physical variable with the strongest correlation to ranking was backhand agility (r=0.72), followed by moderate correlations to overhead medicine ball throw, 10m and 20m (see Table 4.5). The two age groups presented different correlations to peak serve velocity, in U12 females large correlations grip strength (dominant r=0.78, non-dominant r=0.77) and overhead medicine ball throw (r=0.66) were observed. However, in U14 females, only backhand agility showed a significant correlation to serve speed (r=0.55).

Both groups of male players reported significant correlations to peak serve velocity in grip strength, overhead medicine ball throw and backhand agility (See Table 4.5). The strength of correlations in the upper body measures being notable larger in U14 players. The U12 players also had significant correlations to speed (5m r=-0.40, 10m r=-0.51, 20m r=-0.54), forehand agility (r=-0.46) jumps (squat jump r=0.42, countermovement jump r=0.41), which were not found in the U14 group.

Table 4.5 Spearman's correlation coefficients between anthropometric and physical test variables and peak serve velocity (PSV) and National ranking

	Male				Female			
	U12 (n=32)		U14 (n=25)		U12 (n=29)		U14 (n=24)	
	PSV	Ranking	PSV	Ranking	PSV	Ranking	PSV	Ranking
Age (years)	**0.41**	**-0.59**	**0.56**	**-0.51**	0.38	-0.22	**0.62**	**-0.41**
Biological Age (years)	**0.60**	**-0.45**	**0.77**	-0.40	**0.62**	-0.23	0.39	-0.25
Age at Peak Height Velocity (years)	-0.02	**-0.42**	**-0.50**	-0.30	**-0.45**	0.09	0.24	-0.29
Height (cm)	**0.59**	-0.28	**0.75**	0.02	**0.73**	-0.20	0.14	0.06
Sitting Height (cm)	**0.63**	-0.21	**0.63**	-0.18	**0.70**	**-0.46**	0.14	0.04
Weight (kg)	**0.60**	-0.31	**0.74**	**-0.41**	**0.61**	-0.10	0.22	-0.12
Grip Strength Dominant (kg)	**0.52**	-0.25	**0.83**	**-0.57**	**0.78**	**-0.40**	0.04	0.06
Grip Strength Non-Dominant (kg)	**0.60**	-0.34	**0.76**	-0.39	**0.77**	-0.23	0.09	-0.02
Sit and Reach (cm)	0.22	0.15	0.03	-0.20	0.23	-0.27	0.34	-0.39
Countermovement Jump Height (cm)	**0.41**	0.09	0.21	0.25	0.04	-0.26	0.27	-0.12
Squat Jump Height (cm)	**0.42**	0.06	0.01	0.17	0.23	**-0.49**	0.27	-0.13
Overhead Medicine Ball Throw Distance (m)	**0.45**	-0.06	**0.72**	**-0.57**	**0.66**	**-0.48**	0.44	**-0.47**
Forehand Agility (s)	**-0.46**	0.06	-0.12	-0.08	-0.28	**0.54**	-0.31	0.36
Backhand Agility (s)	**-0.43**	0.17	**-0.45**	0.37	-0.14	**0.44**	**-0.55**	**0.72**
5m (s)	**-0.40**	-0.07	-0.08	-0.18	0.02	0.33	-0.18	0.25
10m (s)	**-0.51**	-0.06	-0.11	-0.13	-0.06	**0.40**	-0.34	**0.44**
20m (s)	**-0.54**	-0.06	-0.38	0.09	-0.16	**0.45**	-0.41	**0.48**
Peak Serve Velocity (kmph)		-0.35		**-0.61**		**-0.52**		**-0.78**
Mean Serve Velocity (kmph)	**0.97**	-0.28	**0.98**	**-0.63**	**0.93**	**-0.56**	**0.88**	**-0.77**
Serve Accuracy	0.01	**-0.43**	-0.24	0.00	-0.06	-0.25	-0.15	0.27

*Numbers highlighted in **bold** indicate significant correlation

4.5.3 Relative age effect

The NZ population was found to have a balanced distribution throughout birth years in this sample (2002-2006), across both halves (1st half (1st HY) 49.0% ± 0.30% and 2nd half (2nd HY) 50.9% ± 0.37%) and quarters of the year (Q1-Q4 25.0% ± 0.56%). Table 4.6 and Table 4.7 show the distribution of births for all participants within their age category and birth year.

Relative age effect in Female Players

When analysed by gender, a skew towards players born in the first half of the year (1st HY) was observed in female players across both age categories (U12 1st HY 58.6% and 2nd HY 41.3%, U14 1st HY 58.3% and 2nd HY 41.6 %). This trend was more apparent when only players participating in the main draw of the Nationals (Tier 1) were included in the analysis, where it was observed that 62.4% and 68.8% (U12 and U14 respectively) of players were born in the first half of the year. This aligns with the distribution of birth dates of all female players competing at this playing level (participants and non-participants n=64), where a split of 64.1% 1st HY to 35.9% 2nd HY was identified. The prevalence of players born in the 1st HY across both playing levels (Tier 1 and 3) was more pronounced at U14 level than at U12 (U12:56%:44% and U14:71.8%:28.2%). Interestingly, there was dominance of players born in the second quarter of the year in both age-groups (See Table 4.6), which when analysed independently was consistent across playing level, age categories and birth years. Although 1st HY in U12 were shown to have more advanced maturity, greater anthropometric measures and outperformed 2nd HY in all measured physical fitness parameters, independent t-test comparison of group means showed weight to be the only significant difference (p=0.05, ES=1.3).

Relative age effect in Male Players

A more moderate bias towards 1st HY births was seen across all male participants (U12 and U14) at all playing levels (n=57) participating in this study (54.3% 1st HY and 45.6% 2nd HY), with a similar bias seen within each age category (U12:53.1%:46.8%, U14:56%:44%). However, when separated by playing level, participants competing in Tier 1 were found to have an even distribution between the two halves of the year at U12 (50%:50%) and significantly greater 2nd HY births at U14 level (31.25%:68.75%). Comparison of group means highlighted 1st HY players to have significantly advanced maturity (predicted age at PHV) in both U12 and U14 (U12 ES=1.0, U14 ES=1.4). In U14 players significant differences were noted in height (ES=1.2), weight (ES=1.4), biological age (ES=2.4) and squat jump (ES=1.5) the only significant physical fitness variable.

Table 4.6 Birth date distribution by age group and playing level

Age Group	Playing Level	Birth Year	n	1st Half	2nd Half	Q1	Q2	Q3	Q4
U12 Boys	All Participants (Tier 1-3)	2004-2006	32	17 (53.1%)	15 (46.8%)	9 (28.1%)	7(21.9%)	9 (28.1%)	7(21.9%)
	Tier 1 Participants only	2004-2006	18	9 (50%)	9 (50%)	6 (33.3%)	3 (16.7%)	6 (33.3%)	3 (16.7%)
	TIER 1: All players	2004-2006	32	17 (53%)	15 (47%)	11(34%)	6 (19%)	11 (34%)	4 (13%)
U12 Girls	All Participants (Tier 1-3)	2004-2006	29	17 (58.6%)	12 (41.3%)	5 (17.2%)	12 (41.4%)	8 (27.6%)	4 (13.8%)
	Tier 1Participants only	2004-2006	24	15(62.4%)	9 (37.4%)	5 (20.8%)	10 (41.7%)	6 (25.0%)	3 (12.5%)
	TIER 1: All players	2004-2006	32	18 (56%)	14(44%)	5(16%)	13(41%)	9 (28%)	5 (16%)
U14 Boys	All (Tier 1-3)	2002-2004	25	14 (56%)	11(44%)	8 (32%)	5(20.0%)	3 (12.0%)	9 (36.0%)
	Tier 1 Participants Only	2002-2004	16	5(31.25%)	11(68.75%)	2 (12.5%)	3(18.8%)	3 (18.8%)	8 (50.0%)
	TIER 1: All players	2002-2004	32	9 (28.1%)	23 (71.8%)	4 (12.5%)	5(15.6%)	11 (34.3%)	12(37.5%)
U14 Girls	All (Tier 1-3)	2002-2004	24	14 (58.3%)	10 (41.6%)	7 (29.2%)	7(29.2%)	7 (29.2%)	3 (12.5%)
	Tier 1 Only	2002-2003	16	11 (68.8%)	5 (31.3%)	4 (25.0%)	7 (43.8%)	2 (12.5%)	3 (18.8%)
	TIER 1: All players	2002-2005	32	23 (71.8%)	9 (28.1%)	6 (18.8%)	16 (50%)	4 (12.5%)	6 (18.8%)

Table 4.7 Comparison of 12th and 14th birth year group means between 1st HY and 2nd HY birth dates

		U12 Boys 12th Birth Year only (2004)		U14 Boys 14th Birth Year Only (2002)		U12 Girls 12th Birth Year only (2004)		U14 Girls 14th Birth Year only (2002)	
Test	Half of Year	Mean ± SD	p	Mean (SD)	p	Mean ± SD	p	Mean ± SD	p
Height (cm)	1st 2nd	156.2 ± 4.7 153.8 ± 5.8	0.33	175.5 ± 4.1 165.1 ± 8.8	**0.05**	157.4 ± 5.1 150.8 ± 6.3	0.73	163.5 ± 4.88 162.5 ± 6.76	0.79
Weight (kg)	1st 2nd	43.7 ± 4.6 44.9 ± 6.4	0.66	66.6 ± 1.03 55.0 ± 9.02	**0.03**	48.6 ± 6.01 40.3 ± 6.8	**0.05**	53.5 ± 9.8 54.2 ± 8.4	0.89
Age at peak height velocity (years)	1st 2nd	14.1 ± 0.2 13.8 ± 0.4	**0.04**	13.2 ± 0.95 14.1 ± 0.62	**0.01**	12.1 ± 0.42 12.4 ± 0.37	0.22	12.6 ± 0.4 12.3 ± 0.43	0.31
Biological age (years)	1st 2nd	-1.3 ± 0.2 -1.61(0.41)	0.08	1.4 ± 0.2 0.1 ± 0.6	**0.01**	0.6 ± 0.5 0.1 ± 0.5	0.12	2.2 ± 0.4 2.0 ± 0.5	0.46
Upper Body Strength (Grip Strength Dominant)	1st 2nd	26.3 ± 3.1 27.9 ± 4.8	0.43	45.5 ± 7.5 40.9 ± 9.1	0.38	28.6 ± 5.0 26.1 ± 4.0	0.39	28.5 ± 12.5 33.7 ± 3.5	0.39
Overhead Medicine Ball Throw Distance (m)	1st 2nd	8.1 ± 0.8 8.0 ± 1.3	0.97	11.4 ± 1.6 11.7 ± 1.9	0.80	8.4 ± 1.8 8.0 ± 0.8	0.64	8.4 ± 1.2 8.4 ± 0.8	0.98
CMJ Height (cm)	1st 2nd	28.9 ± 4.5 29.6 ± 7.0	0.82	36.0 ± 5.5 38.4 ± 5.9	0.49	30.4 ± 3.0 28.2 ± 2.4	0.24	31.5 ± 2.0 32.1 ± 2.8	0.74
Squat Jump Height (cm)	1st 2nd	25.3 ± 6.3 24.1 ± 5.4	0.65	35.1 ± 5.0 30.5 ± 2.4	**0.04**	26.8 ± 2.7 23.92 ± 2.2	0.11	27.2 ± 3.5 25.2 ± 2.9	0.33
Speed (5m) (s)	1st 2nd	1.22 ± 0.1 1.18 ± 0.1	0.48	2.31 ± 0.1 2.32 ± 0.1	0.89	1.22 ± 0.9 1.21 ± 0.1	0.94	1.15 ± 0.1 1.17 ± 0.2	0.64
Agility (FHAG) (s)	1st 2nd	2.52 ± 0.1 2.51 ± 0.2	0.88	1.07 ± 0.1 1.12 ± 0.1	0.25	2.54 ± 0.2 2.49 ± 0.1	0.55	2.46 ± 0.2 2.43 ± 0.1	0.76
Serve Velocity (kmph)	1st 2nd	128.3 ± 11.8 133.9 ± 12.5	0.35	159.7 ± 8.7 154.8 ± 11.3	0.46	125.1 ± 19.1 108.5 ± 7.7	0.13	134.8 ± 10.6 122.4 ± 19.1	0.21
National Ranking	1st 2nd	31.0 ± 34.9 31.6 ± 20.1	0.96	31.8 ± 51.1 11.2 ± 7.2	0.48	19.5 ± 34.5 29.4 ± 22.1	0.59	10.6 ± 13.4 55.2 ± 51.7	**0.07**

*Numbers highlighted in **bold** indicate significant correlation

4.6 Discussion

The aims of this study were to determine the growth, maturation and physical fitness characteristics of U14 tennis players in NZ and to explore relationships with tennis performance. This was with a view to enabling comparison with existing trends and traits of international peer groups and facilitate better understanding of the training requirements of young players. A further aim was to determine if a relative age effect existed amongst NZ junior players, in addition to establishing the influence of maturation on performance in this cohort.

4.6.1 Physical fitness characteristics and Tennis performance

U12

Research of the relationship between fitness characteristics and performance have highlighted the superior upper body strength and power qualities of elite juniors in comparison to their sub-elite peers (Fett et al., 2017, Ulbricht et al., 2015a). The results of this study are mostly in agreement with these findings regarding factors determining both ranking and serve velocity. At U12, female ranking appeared to be influenced by overall athletic ability with moderate correlations to upper body strength and power, lower body strength, speed and agility. These results are in slight contradiction to those found by Kramer et al. (2016a), who assessed four physical variables (upper body power, lower body power, speed and agility), finding upper body power to be the only variable not to be predictor of level of performance within U14 female players. In the present study, the strongest relationship to U12 ranking was observed. Further analysis via comparison of playing level groups, showed elite players performed significantly better ($p \leq 0.05$) in measures of upper body strength (grip strength) and power (overhead medicine ball), lower body strength (squat jump), speed and agility (forehand and backhand agility, 10m 20m). These findings have been previously noted in older age groups (Ulbricht et al., 2015b, Ulbricht et al., 2015a, Fett et al., 2017). In alignment with the only other study to compare physical performance tests to serve velocity, present results showed these upper body strength and power qualities had the largest correlation to serve performance, reinforcing the particular importance of these qualities for female tennis performance (Fett et al., 2018).

In contrast, the influence of physical performance variables in relationship to ranking for U12 males, appears to be minimal at this stage of development. Age and maturity measures (biological age and predicted age at PHV) were only moderately correlated to ranking. Additionally, no significant differences in physical performance measures were observed between playing level groups. However, elite players were faster in both linear speed and agility over short distances which has been previously been described in players age 10-13 years (Kramer et al., 2017a). This may also provide further support of earlier research suggesting that these speed and agility qualities may be the first physical attributes to influence competitive levels of prepubescent players (Kramer et al., 2017a, Roetert et al., 1992, Birrer et al., 1986). This seems logical given the high demand for change of direction and acceleration inherent in the sport (Kovacs et al., 2008b, Kovacs, 2009).

U14

Overhead medicine ball throw was a key determinant of U14 ranking for both genders, alongside chronological age and serve velocity. For males, the only other significant physical variable was upper body strength (grip strength). These two factors also had the highest correlations to serve velocity, equal only to previously discussed height and mass characteristics and in agreement with findings from a much larger sample size (n=1019 females and males) (Fett et al., 2018). These interrelationships highlight the influence of maturity on the key performance variables in this age group, as players transition towards senior tennis the requirement to be able to produce higher stroke velocities increases (Kovacs and Ellenbecker, 2011b). It is well established that the physiological advantages (both biomechanical and hormonal) afforded by advanced maturity enables increases capacity for greater force production (Lloyd et al., 2014). The strong correlations between players' height, weight and biological age with physical performance measures, particularly with upper body strength and serve velocity and their subsequent influence on ranking are potentially reflective of how this may transpire into a performance advantage.

As with their younger counterparts, U14 female ranking also showed moderate correlations to linear speed and large correlation to backhand agility speed, which was not observed in male players. Previous studies have shown speed and agility qualities by elite players of both genders to be superior to that of sub-elite (Fett et al., 2015, Fett et al., 2017). However, there are conflicting opinions as to whether these attributes influence ranking post puberty. Evidence suggests that it does have the capacity to differentiate between playing levels (Kramer et al., 2016b, Kramer et al., 2016a), but not necessarily the ability to discriminate between a fairly homogenous group of players (Kramer et al., 2017a). However, drawing from the limited longitudinal data available, higher ranked female players have been shown to have a higher level of speed and agility at U14, an advantage they maintained at U16, and further highlights the importance of these qualities within the junior female game (Kramer et al., 2016a). One possible explanation may be that due to the physical demands of junior girls tennis, where performance analysis has shown junior girls to have greater foot speeds and changes of direction per point in comparison to professional women's tennis, creating up significantly more work per point (median 84%) and per game (median 56%) (Kovalchik and Reid, 2017). By comparison the overall physical demands of male tennis increases exponentially as players mature from junior boys to professional men's tennis (Kovalchik and Reid, 2017). As a result, male players must have increasingly high levels of all-around physical fitness to remain competitive at elite level. Therefore, the importance of specific physical qualities outside of upper body power qualities which appear predominant during adolescence may be less apparent.

Interestingly, in addition to the relationship with ranking, backhand agility speed had a large correlation to serve velocity in both U14 males and females. No correlations to forehand agility were observed in either group, but moderate correlations were seen to linear speed. It could be speculated that as both the serve and the change of direction on the backhand side are dependent on loading of the same leg (left leg for right handers, right leg for left handers). This result could be more indicative of lower limb strength levels and the contribution of strength to both serve and effective change of direction, and the increasing importance of these factors with age given the rising velocity demands of the sport as players mature. Injury prevention research has previously identified the presence of lower-limb strength asymmetries within young tennis players and suggested that long term these can effectively create a limit on sports-specific speed performance (Sannicandro et al., 2014)

4.6.2 Maturity and Tennis Performance

Serve velocity was the only variable to be correlated to ranking across the majority of groups, which aligns with previous research that has highlighted the serve as the most important shot in the game and a key performance indicator (Kovacs and Ellenbecker, 2011b, Ulbricht et al., 2015a, Fett et al., 2018). It is apparent from the results that serve velocity plays a key role in determining ranking within young NZ tennis players. This may be overshadowed by serve accuracy in U12 males. The highest correlations were seen within the older age-group (U14), where both technical proficiency and the influence of physical maturity are likely to be greater. Although chronologically older players have an increased probability of being biologically more advanced, this is not always the case due to the variation in the individual timing of the onset of puberty (Baxter-Jones et al., 2005). Across both age groups biological age and APHV was shown to have stronger positive correlations to anthropometric measures than chronological age. This Indicates that as with previous research, more mature players within these cohorts are taller and heavier (Myburgh et al., 2016a). Maturity appears to be a consistent predictor of serve velocity for both genders at all ages, while anthropometric measures play a particularly large part within the two groups which have the most variation in stage of maturation (U12 females and U14 males). Within these groups players are divided between pre-PHV, circum-PHV and post-PHV meaning more mature players can use their biomechanical advantage of increased limb length and mass.

Previous studies have highlighted this relationship, suggesting that the ability of taller players to hit the ball at a greater height according to biomechanical principles theoretically enables them to serve at higher speeds (Bonato et al., 2015, Vaverka and Cernosek, 2013, Fett et al., 2018, Hayes et al., 2018). This relationship is still present to lesser degree within U12 males whilst all players are pre-PHV, but non-existent within U14 females where all players (except 1) were at least one-year post-PHV. Potentially, in both cases this is because the participants were relatively homogenous in terms of stage of maturation meaning anthropometric differences are less significant within a cohort of this sample size. At this point technique and other physical attributes may have a stronger influence on the serve velocity of these players. Although proving technical proficiency may be complex, comparison of group means of elite (players ranked in the top 16) vs sub-elite (>16) support this theory, with higher ranked players serving significantly faster ($p \leq 0.05$) than their lower ranked counterparts within most groups. The U12 males were the exception where average speed was faster but not at a significant level. This exception may be explained by the limited number of top 16 players (elite) vs lower ranked players (sub-elite) within this group (n=5 vs n=27), not enabling a true reflection of the differences between competitive groups. Alternatively, these results may also be in accordance with current opinion that success in prepubescent players can be largely attributed to skill level and the ability to produce, consistent and accurate shots rather than physical variables (Ulbricht et al., 2015a, Roetert et al., 1992). Moderate correlation found only in the U12 male group in this study between ranking and serve accuracy supports this theory, with elite players recording 27.5% better accuracy on average when compared to sub-elite players. This suggests that better players prior to puberty, may be rewarded more for placement rather than power at this point, placing greater dependence on skill and less on physical ability.

4.6.3 Relative Age Effect

The results showed the presence of the relative age effect amongst female participants to be in alignment with previous research with birth distribution more heavily weighted towards 1st HY births (Edgar and O'Donoghue, 2005), this was more apparent with increasing playing level and age. Additionally, although the skew towards those born in the first half of the year was greater in this particular cohort, the findings are similar to those reported in a larger sample of 211 elite female players where a divide of 60.6% 1st HY to 40.4% 2nd HY was observed (Edgar and O'Donoghue, 2005). Overall, analysis of relative age effect in all male participants also corroborated with existing literature with a moderate bias towards players born in the 1st HY (Loffing et al., 2010, Agricola et al., 2013). However, further breakdown by playing level produced contrasting results with 68.8% of U14 male participants (n=13) found to be born in 2nd HY. To ensure this was reflective of all national level players competing in 2017, the birth dates of the entire main draw (n=32) were collated from a public database and analysis showed similar trends with 71.8% born in the 2nd HY. This effect appears to be a contradiction of the factors which appear to be the strongest influence on performance in this category, where chronological age was shown to have one of the strongest correlations to ranking (r=0.56). Physically, the 1st HY group results showed the older players to be taller and heavier, but the difference between groups was not statistically significant (p=0.27). Although there was substantially greater variance in the time to PHV within the 1stHY group (Mean 1st HY=0.22 ± 0.9yrs vs 2nd HY 0.08 ± 0.5yrs), the difference in maturity was not significant (p=0.66). No explanation can be given as to why this group presents a trend contrary to that in all other published research. This may give support to speculation that males who are truly physically superior are lost to more popular sports within NZ which benefit from increased size and maturity, such as Rugby Union. The fact that this trend is more obvious at U14, aligns with the fact that most youth athletes will have started to specialise around the age of 13-14, meaning they are less likely to play more than one sport at national level (Balyi and Hamilton, 2003).

4.6.4 Limitations

Although this study was able to provide a good first insight into the trends in physical characteristics of NZ junior tennis players, it is not without limitations. One of the main limitations is the lack of a large muscle group strength test such as squat, bench or mid-thigh pull. It was not practically possible for this cohort but would have provided valuable information on the relationship between strength and performance in this age group. It Is also important to remember that although several the correlations align with previous literature, these relationships do not equal causation or can necessarily predict performance directly and therefore should be interpreted with caution.

4.7 Practical Applications

For both genders, it was apparent that serve velocity may have the most significant influence on performance from a young age, and given the rising velocities present in professional tennis this appears to continue to be the case as players mature. The development of serve technique is an existing priority for most tennis coaches working with elite players as this shot is recognised as the most important shot in the game (Kovacs and Ellenbecker, 2011b). While this suggestion lacks empirical evidence, traditionally serve practice takes place at the end of the lesson when the player may already be fatigued and for significantly less time than other aspects of the training session. It therefore may be prudent, especially when learning such a complex skill, that this take place earlier in the session when the athlete is mentally and physically fresher and that more time within practice is allocated towards its purposeful practice.

From a S&C perspective, it may also be important to ensure the development of specific physical qualities shown to influence serve performance. This study focused on the physical qualities influencing performance at U12 and U14 and found upper body power and strength to be particularly relevant to both genders, which is in agreement with previous studies with substantially larger sample sizes (Ulbricht et al., 2015a). Although the impact is less apparent among prepubescent males, the significant impact at U14 potentially indicates that early development of these qualities may be beneficial to future performance. The benefits of commencing strength training pre-PHV is well documented (Faigenbaum and Myer, 2010, Behringer et al., 2011), but this will require further research to quantify the long term effect of this in regards to impact on tennis performance. Previous research has highlighted the superior speed and agility of elite female players in comparison to sub elite and this study has supported these findings (Kramer et al., 2016a), additionally showing these attributes to be more influential in the young female players than in male players. This does not necessarily indicate these qualities are not important for the junior male game, rather it may reflect greater variation in movement skills of young female players in this cohort and comparable homogeneity of male players at this level. It may be worth considering allowing more time for development of speed and agility skills for young females, given their contribution to enhanced performance.

As for any practitioner working with youth populations being mindful of the influence of maturity and anthropometric studies on the above physical characteristics is of upmost importance. This is applicable for both S&C coaches prescribing training programmes and coaches responsible for talent identification and team selection. The findings of this study indicate that the presence of RAE amongst junior NZ players is similar to that which has been reported in previous literature using international cohorts (Pacharoni et al., 2014, Agricola et al., 2013, Ulbricht et al., 2015b), with an overall bias towards players born in the first half of the year. Testing results further highlighted that both advanced chronological and biological age within the different age groups has a positive influence on variables strongly correlated to performance.

Chapter 5 – The training characteristics of New Zealand junior tennis players and their relationship to tennis performance

5.1 Preface

The findings of chapter 4 suggested that the NZ trends in maturity and physical characteristics in relation to tennis performance do not differ greatly from those observed in the cohorts of previous studies in other countries (Fett et al., 2018, Ulbricht et al., 2015a). Brouwers et al. (2012) reported that apparent advantage of having greater tennis training hours and tournament experience at an early age is lost post puberty. This suggests that talent indicators for success at professional level shift towards, physical abilities, anthropometric qualities, tennis skill and psychological qualities (Brouwers et al., 2012, Unierzyski et al., 2003). Previous research has neglected to examine the influence of players past training experience on performance, with limited research referencing training volumes (Fett et al., 2017, Fett et al., 2015). In addition, the limited studies that have included analysis of physical training volumes have failed characterise the type of training completed leaving a gaps in the literature in this area. As physical development is to some extent a controllable factor, this raises the question as to how the physical training of junior tennis players in NZ can be improved. In order to identify this, it was necessary to ascertain current S&C practice within the NZ junior tennis population. This will enable comparison to the limited empirical data of international peers and recommendations made by National federations for the development of elite players.

5.2 Introduction

New Zealand is one of the world's most successful sporting nations on a per capita basis (Prathap, 2016), with a reputation for the resourceful and resilient nature of their athletes. This enables them to exceed expectations of a small, isolated country. Despite relative success in doubles, in singles tennis there has been less success with only one player gaining a top 100 ATP or WTA rankings in the last twenty years. A stepwise regression analysis of junior rankings showed those who gained a top 20 ITF junior ranking had a 90% likelihood of going onto achieve a professional ranking (Reid et al., 2007b). Even this early benchmark has rarely been achieved in recent years by NZ players. Junior top 20 players typically come from larger, more populous nations such as USA, France, Argentina and (Reid et al., 2007b, Reid et al., 2009a). However, some smaller and perhaps less affluent nations did also make it into the list of top 10 countries during both 6-year periods analysed (Reid et al., 2007b).

As a National federation focusing on trying to produce top level professional players the training and competition volumes currently advocated to achieve this are summarised in Figure 5.1 below

(Accessed on www.tennis.kiwi). These recommendations are formed from data collected by other successful federations including Tennis Canada, Tennis Australia, Lawn Tennis Association (Great Britain), French Federation for Tennis and the United States Tennis Association. The number of NZ's promising young players who have training programmes that align with the suggestions made by the governing body is unknown and it is also unclear if is a factor contributing to apparent lack of professional success.

Currently little is known about training characteristics of NZ junior players but based on anecdotal information it is hypothesised that significantly less importance is placed on physical training and that total training volumes are substantially less than their international counterparts. Empirical research in other countries has gathered data on training characteristics to ascertain the relationship to the performance of elite junior players (Ulbricht et al., 2015a, Fett et al., 2017, Fett et al., 2018, Ulbricht et al., 2013, Fernandez-Fernandez et al., 2013, Fernandez-Fernandez et al., 2018, Kramer et al., 2016a). Subsequently this has provided data to inform exercise prescription and recommendations around physical training for junior players. In order to do the same in NZ, empirical information was required to form a foundation of data on current practice. Therefore, this study aimed to be the first to do this via surveying current training characteristics of NZ junior players.

PLAYER DEVELOPMENT RECOMMENDATIONS

Players, coaches and parents often ask what volumes of playing and training are required for a promising young player to break through into the top levels of junior and professional tennis. The following recommendations have been formed from data collected from successful tennis federations including Tennis Canada, Tennis Australia USTA, FFT and the LTA.

	PLAYING				PRACTICING			
AGE	#OF TOURNAMENTS PER YEAR	SINGLES MATCHES PER YEAR	DOUBLES MATCHES PER YEAR	# OF PEAKS	FITNESS HOURS PER WEEK	TENNIS TRAINNIG PER WEEK	OTHER MATCHES PER YEAR (Interclub/ practice matches)	TOTAL HOURS PER WEEK
5-6 years old	0			0	4 (2.5 of an other sport)	1-4	15-25	5-8
Boys 7-9 Girls 7-8	7-12	21-36		0	4.5-5 (2.5-3 other sports)	4-9	25-40	8-12
Girls 9	8-10	24-30	16-20	0	4.5-5.5 (3 other sports)	6-8 hs(2-3 privates included)	30-40	10-15
Girls 10	10-15	30-45	20-30	0	5-6 hs (3 of other sports)	8-10 (2-4 privates)	30-40	12-17
Girls 11	10-15	30-45	20-30	0	5.5-7 (3)	10-12 hs (2-4)	30-40	15-18
Boys 9-10	10-15	30-45	20-30	0	5-6hs (3)	8-10(2-4)	30-40	15-18
Boys 11-12	15	45-60	30	0	5.5-7hs (3)	10-12	48	16-18
Girls 11-12	15-20	45-60	30	0	4-5	12-14	48	16-18
Girls 13-14	15-20	45-60	30	2-3	5-8	12-14	48	18-24
Boys 13-15	15	45-60	30	2	5-8	12-14	48	20
Girls 15-16	24-28	72-84	48-56	3	6 if Tennis priority 10 if physical priority	18-22	48	28
Boys 16-18	27-30	71-90	54-60	3		18-20	48	28
Women 17-21	22-26	66-78	44-56	3		22	N/A	28
Men 19-23	27-30	56-60	54-60	6		22-24	N/A	28
Women22+	22-26	66-78	44-56	6		22	N/A	24
Men 24+	20-25	40-50	50	6		18-20	N/A	24

Figure 5.1 Current Player Development recommendations advocated by Tennis New Zealand (National Governing Body)

5.3 Methods

5.3.1 Experimental Approach to the Problem

Data collection for this study took place at the same event described in Chapter 4 (National championships and a concurrent lower grade tournament – Tier 3), which occurred simultaneously at the same location. This allowed for the inclusion of players from all geographical regions and presented an opportunity to compare elite players to sub-elite players within these age groups at the same time.

5.3.2 Subjects

Ninety-nine players (56 males and 43 females) aged 10-14 years participated in the study. Participant age and physical characteristics are presented in Table 5.1. Players volunteered and were included if they were participating in either the Tier 1 (National Championships) or Tier 3 (lower grade) tournaments. Before commencing testing, all subjects were fully informed about the purpose and procedures of the study. As subjects were all under the age of 16 years old, written assent was gained in addition to informed written consent of the parent/guardian. The Auckland University of Technology Ethics Committee approved this study (AUTEC reference:16/131).

Table 5.1 Descriptive statistics of all subjects

		U12 Females	U12 Males	U14 Females	U14 Males
n		24	32	19	24
Age	Years	11.6 ± 0.8	11.8 ± 0.9	14.0 ± 0.6	13.9 ± 0.6
Handedness	Right	89.7%	84.4%	92%	92%
	Left	10.3%	15.6%	8.0%	8.0%
National Ranking	Age group	31.2 ± 29.9	52.2 ± 38.5	39.3 ± 40.0	5.6 ± 35.6

5.3.3 Procedures

All players volunteered to participate in a questionnaire to obtain data on their training characteristics (See Appendix F). The primary researcher remained present to answer any questions. To improve reliability all participants were recommended to fill in the questionnaire with the aid of their parent or coach as most were also present at the time. The individual workloads for current number of tennis training and physical training hours per week were obtained via open-ended questions. Numeric multi-choice answers were provided regarding information on training history (age started tennis training and physical training). Multi-choice answers were also provided regarding participation in other sports, structure of physical training (supervision), number of tournaments per year and number of hours training for other sports. Data on injury frequency and severity was also obtained, but difficulty recalling this information in 3 of the 4 groups led to a high percentage of players not reporting (28-38%) and subsequently this data was not included in analysis (See Appendix G).

5.4 Statistics

Open-ended questions regarding with numerical answers were presented via means ± SD and multi-choice answers presented by frequency of answer as a percentage of all players who participated within each age-group.

Data was checked for normality via the Shapiro-Wilk test and as ranking data was not normally distributed, Spearman's rankings were used to calculate correlations between ranking and weekly training volumes (tennis, physical and total). Correlation strength was described as per (Cohen, 1988), where threshold values were 0.1-0.3 (small), 0.3-0.5 (moderate) and <0.5 (large).

Differences in mean training volumes between playing level groups (elite vs sub-elite) were compared using an independent samples t-test. Levene's Test was used to evaluate equal variance and significance was identified at $p < 0.05$. Effect size was calculated to describe the magnitude using Hedges' g and this size was defined as in line with definitions of size of difference (Fritz et al., 2012). The strength of the relationship was considered as ≥ 0.2 small, ≥0.5 medium and ≥0.8 large (Fritz et al., 2012).

5.5 Results

On average U12 females participated in 8.5 ± 5.0 hrs of tennis training per week and boys slightly less at 8.0 ± 3.1 hrs, this did not change substantially at U14 level, (females 9.6 ± 5.0 hrs, males 8.6 ± 3.2 hrs) (See Table 5.2). Within both age categories when compared by playing level (National ranking < 16 vs National ranking >16) tennis training hours were one of the key differentiators between elite and sub-elite players, with elite players training significantly more (See Table 5.5). In both female age groups, the difference was significant ($p \leq 0.05$). Additionally, on average elite players played more tournaments per year and started playing tennis at a younger age.

At U12 half of players reported participating in physical training (55% females 53.1% males) with an average of 1.7 ± 0.9 hrs (females) and 1.6 ± 1.0 (males) dedicated per week to fitness development. Analysis by playing level group showed that participation in physical training (100% vs 42.1%), physical training volume and total weekly volume ($p<0.05$ ES=1.8) was higher among the female elite group in comparison to their sub-elite counterparts (See Table 5.5). In U12 males similar between group differences in training volumes were observed but these were not statistically significant. Females most frequently reported their fitness sessions to be led by a specific fitness coach (34.5%), followed by their tennis coach (17.2%) (See Table 5.3). The reverse was true for males with their tennis coach being most frequently reported to lead physical training (28.9%) and a fitness coach the second most reported (21.9%).

In U14 females around a 10% decline in overall participation in physical training was observed and there was minimal change in the average weekly training volumes for females in comparison to the younger age group (2.0 ± 1.4 hrs). As before higher values were seen in elite players in participation in weekly physical training (88.9% vs 30.0%) and physical training volume (2.7 ± 1.4 hrs vs 1.2 ± 0.8). Elite players most frequently reported that their physical training was led by a fitness coach (88.9%) with most of this taking place at their tennis training venue. Whereas in contrast sub-elite players most frequently reported that their physical training was led by their tennis coach (50%).

Overall involvement in physical training was much higher in U14 males than in U12, reported at (75% vs 58.6%). Elite players reported higher values in comparison to sub-elite (91.7% vs 76.5%). The difference between elite and sub-elite in overall weekly volume was not significantly different (3.0 ± 1.7 hrs vs 2.5 ± 1.4 hrs). Both groups most frequently reported their physical sessions were led by a specific fitness coach (elite 33.3%, sub-elite 54.1%) but unlike the other age groups in elite players this was equal to sessions being self-led (33.3%) and this was the second most common method for sub-elite players (36.4%).

Regarding participation in other sports, female players across both age groups were more likely to have already specialised in tennis than males of the same age. Among U12 females 82.6% participated regularly in other sports, with this dropping to 62.5% within the elite group and rising to 93.3% in the sub-elite group showing another disparity between playing levels. At U14 only 42.1% played other sports and only 22.2% of those in the top 16. By comparison 93.1% of U12 males participated in other sports and this occurred across both playing levels (elite 100%, sub-elite 90.9%). There was only small drop off at U14 overall, with 78.3% of all players still participating in other sports, but a noticeable decline within the elite group to 63.6% whereas 91.7% of sub-elite maintained participation in other sports on a weekly basis.

Table 5.2 Training characteristics: Training experience and volumes

		U12 Females	U12 Males	U14 Females	U14 Males
Age Started Playing Tennis	Years	5.6 ± 2.07	4.8 ± 2.0	7.0 ± 2.21	7.3 ± 2.4
Tennis Training Volume	Hours per week	8.5 ± 5.0	8.0 ± 3.1	9.6 ± 5.0	8.6 ± 3.2
Competition Volume (Tournaments per year)	0-5	3.5%	6.3%	5.3%	8.3%
	5-10	37.9%	37.5%	26.3%	16.7%
	10-15	34.5%	31.3%	26.3%	47.8%
	15-20	13.8%	12.5%	31.6%	26.1%
	20-25	3.4%	3.1%	0%	0%
	25+	3.4%	9.4%	10.5%	0%
	DNR	0%	0%	5.3%	4%
Participation in Physical Training	Yes	66.7%	58.6%	57.9%	75.0%
	No	8.3%	0%	0%	8.3%
	Sometimes	25%%	415%	42.1%	16.7%
	DNR	0%	9.4%	0%	0%
Physical Training Volume	Hours per week	1.7 ± 0.9	1.6 ± 1.0	2.0 ± 1.4	2.8 ± 1.6
Age started Physical training	Years	10.2 ± 1.0	10.0 ± 0.9	12.4 ± 1.0	11.4 ± 1.4
	DNR	20.7%	28.1%	0%	8%
Total Training Volume (Tennis & Physical)	Hours per week	10.2 ± 5.5	9.5 ± 3.6	11.6 ± 5.7	11.6 ± 4.5

DNR: Did not report

Table 5.3 Training characteristics: Physical Training specifics

		U12 Females	U12 Males	U14 Females	U14 Males
Physical Training Lead By	Fitness Coach	34.0%	17.9%	10.5%	4.2%
	Fitness Coach at Tennis	10.3%	25.0%	52.6%	33.3%
	Tennis Coach	17.2%	32.1%	15.8%	12.5%
	Parent	10.3%	10.7%	0%	4.2%
	Self-led	6.9%	14.3%	0%	33.3%
	Combination of above	0%	0%	21.1%	8.4%
	DNR	20.7%	12.5%	0%	4.1%
Participation in Other Sports	Yes	82.6%	93.1%	42.1%	78.3%
	No	13.0%	6.9%	36.8%	21.7%
	Sometimes	4.3%	0%	15.8%	0%
	DNR	1 player	3 players	1 player	1 player
Training volumes in other sports	0	9.1%	3.6%	38.9%	21.7%
	0-2	36.4%	35.7%	33.3%	26.1%
	2-4	40.9%	46.4%	16.7%	34.8%
	4-6	9.1%	14.3%	11.1%	17.4%
	6-8	0%	0%	0%	0%
	8+	4.5%	0%	0%	0%
	DNR	2 players	4 players	1 player	1 player

DNR: Did not report

Table 5.4 Spearman's correlations between training volumes and National ranking

	Males		Females	
	U12	U14	U12	U14
	Ranking	Ranking	Ranking	Ranking
Tennis training hours per week	-0.21	**-0.42**	**-0.47**	**-0.57**
Physical training hours per week	-0.30	-0.26	-0.12	-0.41
Total training hours per week	-0.22	-0.36	**-0.47**	**-0.58**

*Bold font indicates significant change in mean

Table 5.5 Independent T-test results comparing playing level group means of elite (<16) to sub-elite (>16) players.

	Males								Females							
	U12				U14				U12				U14			
	>16	<16	p	Hedges' g	>16	<16	p	Hedges' g	<16	>16	p	Hedges' g	<16	>16	p	Hedges' g
Tennis training hours per week	9.2 ± 4.8	7.8 ± 2.8	0.57	0.44	9.5 ± 3.1	8.0 ± 3.3	0.28	0.47	13.2 ± 4.3	6.2 ± 3.5	**<0.01**	**1.8**	12.0 ± 4.8	7.4 ± 4.2	**0.04**	**1.0**
Physical training hours per week	2.2 ± 1.9	1.5 ± 0.9	0.49	0.67	3.0 ± 1.6	2.6 ± 1.5	0.51	0.32	2.3 ± 0.7	1.5 ± 0.9	0.06	0.9	2.7 ± 1.5	1.3 ± 0.8	**0.01**	**1.2**
Total training hours per week	11.0 ± 6.2	9.2 ± 2.9	0.56	0.50	12.5 ± 4.6	10.5 ± 4.3	0.40	0.45	15.5 ± 4.5	7.6 ± 4.0	**<0.01**	**1.8**	14.8 ± 5.8	8.8 ± 4.1	**0.02**	**1.2**

***Bold** font indicates significant change in mean

5.6 Discussion

The results of this study provided an insight as to current practices among NZ junior players. The main findings demonstrated that overall participants in this study reported lower average tennis training volumes than recommended guidelines and most published literature.

Data obtained on physical training volumes showed the greatest disparity between NZ players and those reported in previous studies and/or recommendations from other National federations. Players in this cohort reporting notably lower volumes than their international counterparts (Unierzyski, 2002, Mabon, 2016). Although elite players were found to have higher training volumes in tennis, physical and subsequently total hours per week in comparison to sub-elite players, these volumes could generally be placed below or at the lower end of the spectrum for the suggested training volumes for elite player development. The differences between group means were only found to be statistically significant ($p<0.05$) in female players in both U12 (tennis and total volumes) and U14 (tennis, physical and total volumes). Regarding understanding the infrastructure of current S&C practice with junior tennis players in NZ, there was evidence of variation in who is delivering S&C training across the age-groups and playing level. Lastly, data obtained on participation in other sports was reflective of the fact that girls specialised earlier, with elite players generally doing so earlier than sub-elite players.

5.6.1 Tennis training volumes

It has been frequently observed that even from a young age 15-20 hours a week are dedicated to tennis training in junior players (Crespo and Miley, 1998). Research advises against early specialisation and encourages participation in other sports (Balyi and Hamilton, 2003), however this can prove difficult to avoid if trying to achieve these training volumes around full-time schooling. Sparse guidelines exist as to when players should be undertaking these training volumes or specific age recommendations.

The tennis training volumes reported by participants in this study, demonstrated that at U12 weekly hours dedicated to tennis in both genders met the lower end of guidelines recommended by Tennis Australia (8-12 hrs) (Mabon, 2016). This is notably lower than that recommended by Tennis NZ (Males 11-12 yrs: 10-12 hrs, Females 11-12 yrs: 12-14 hrs). Also lower than empirical findings of Unierzyski (2002) (10-12 hrs) and a more recent publication by the same author for the International Tennis Federation proposed 520-600 total tennis training hours per year at age 12 (Unierzyski, 2002). Similarly, the LTAD plan of Tennis Canada suggests 10-12 hours of tennis training per week, building to 12-14 hours by the end of this stage for girls due to their advanced maturation (Accessed on www.tenniscanada.com).

At U14 although there was a small increase seen in mean values for both male and female players, both groups stayed below 10 hrs per week, which aligns with 3 intervention studies reporting an average tennis training time of 8-10 hrs per week for three cohorts of elite or nationally ranked male U14 players (Fernandez-Fernandez et al., 2018, Fernandez-Fernandez et al., 2012, Fernandez-Fernandez et al., 2013). However, this is considerably lower than published guidelines from national governing bodies and players would need to be tracked longitudinally to understand the impact of this. By comparison Tennis Canada recommend 12-14 hrs of tennis training (U14 females and U15 males). The amalgamation of data drawn from multiple federations forming Tennis NZ's guidelines also advocates 12-14 hrs. Guidelines from the International Tennis Federation suggest 600-800 training hours per year by age 14, equating to 11.5-15hrs per week. Allowing for subtraction of tournament weeks away from total training weeks (which also increases with age) and rest, this likely works out closer to 15-20hrs as previously observed (Unierzyski, 2005).

The literature and published guidelines are focused on elite juniors, and as this cohort is inclusive of sub-elite players this information may be misleading. As expected, elite players in this study had higher average tennis training volumes than their sub-elite counterparts in all age groups and genders. The difference was statistically significant in both female age groups with large ES observed (See Table 5.5). By differentiating players by level, the average tennis training volumes for the elite players were more aligned with recommended and observed volumes. Closer analysis revealed that although girls appeared to have higher training volumes than boys within both age groups, much greater variation existed within the values they reported. Therefore, it is possible that within this sample size a small number of players had significantly greater training volumes than the other players (18-20hrs per week) therefore skewing the mean value. This suggests that although a small minority of players have weekly training schedules schedule similar to those seen outside of NZ, this is not the norm even at elite level. A larger sample size would be beneficial to clarify this theory. Additionally, this may be the first indicator that NZ players train less than their international counterparts and could be clarified by using a larger sample size. Lastly, future research would benefit from including information detailing how players divide these training hours between private sessions, group sessions and matchplay.

5.6.2 Physical and Total Training Volumes

Perhaps the greatest disparity between NZ players and others may be involvement in physical training and subsequently total training volume. This may be significant as the only other study to relate training volumes to tennis performance (ranking), found statistically significant relationship with total training volumes ($r=-0.78$, $p <0.01$) and volume of physical training to measures of athletic performance shown to influence tennis performance (upper body strength and power, r=0.62-0.65, p<0.05) (Fett et al., 2017). At U12 58-66% of the participants engaged in regular physical training, and of these players only 44.3% of females and 42.9% of males completed this training this under the supervision of a specific fitness coach (inclusive of S&C coaches, personal trainers etc.). The remaining players reported completing physical sessions by themselves, with a tennis coach or parent. At U14 overall participation in physical training increases, while supervision of this training by a fitness professional decreases and a greater number of players lead their own sessions. Whether this is a safe or effective method of conditioning for the sport at elite level, must be questioned given the lack of NZ players meeting early benchmarks in junior tennis or indeed progressing onto senior international success.

As seen with the results in physical performance tests in Chapter 4, there is a significant difference between the training characteristics of females of different playing levels, this difference was not seen between males at U12. This aside, elite girls were much more likely to take part in structured physical training (80%) and had significantly higher total training volumes than sub-elite (ES=1.2). Conversely, a greater number of sub-elite players were involved in other sports on a weekly basis, which may also allow development of FMS needed at this age (Balyi and Hamilton, 2003). However with an average of 2.3 ± 0.7 hrs physical training for elite female players and the majority of these completing 0-2hrs of other sports (77.7%), it is unlikely this group are achieving the same volumes of total physical training (including other sports) as recommended by National federations for this age group (Tennis Australia 6-9hrs, Tennis Canada 5.5-7hrs) (Mabon, 2016). Tennis NZ's own guidelines recommend 5.5-7 hrs for males (including 3 hr of other sport) and 4-5 hrs for females (physical training only). The majority of U12 males (93.1%) maintained participation in other sports and most doing 2-4hrs per week, perhaps bringing them closer to lower end of the recommended physical hours. It is acknowledged that a bigger sample size would provide a more accurate reflection of physical training volumes in this group and is a limitation of this study. Comparison of group means showed no significant difference between training volumes of different playing levels in this age-group, which may have been influenced by the low number of elite players creating an uneven split and potentially not a fair representation of the wider population. Still, a similar trend was found in Chapter 4 regarding physical characteristics and this homogeneity in training characteristics may potentially explain causation for that trend. It has been previously established that the impact of physical prowess in not evident until later in maturation among male tennis players (Roetert et al., 1992) and it could be theorised that what a player does in regard to athletic development during this time period may not be evident until later on, meaning more longitudinal research is required to understand the true long term impact of training.

At U14, mean physical training governing body guidelines increase to 5-8 hours per week, and as it is assumed at this age that most elite tennis players have specialised by this age and inclusion of training hours in other sport is not included in total physical training hours as with younger players (www.tennis.kiwi, www.tenniscanada.com). Elite U14 players in this study reported higher weekly training volumes than U12 in both physical training and total training volumes. This demonstrates the significantly greater volumes in both parameters than sub-elite (ES=1.2 and 1.2 respectively). Despite this difference, for 82% of elite females this is their only physical training, as only 22.2% play other sports on a regular basis, leaving them significantly below the recommendations. In contrast, over half of elite male players-maintained participation in other sports, yet for a third of them this was a minimal 0-2hrs per week, meaning that is more probable that the majority of players fall short of the time recommended to dedicate to athletic development. This information is perhaps reflective that female players specialise a little earlier than males in New Zealand, which aligns with data demonstrating female players on average achieving peak junior rankings earlier and transitioning to professional tennis at younger age (Reid et al., 2009a, Brouwers et al., 2012).

5.6.3 Limitations

As with any data based on the recall ability of youth athletes, human error is possible and was the biggest limitation to this study and therefore caution is advised when interpreting the results. To minimise the errors made in historical recall, assistance from a parent or coach was recommended, as the majority were on the site this was possible, which hopefully means the data can be trusted to be relatively reliable.

One question regarding at what age players commenced physical training had a particularly high percentage of players that did not report (DNR) in the U12 age group. This does limit the ability to make many definitive conclusions on this topic. For the majority it was known that the reason for this, was in fact that they had not started physical training yet and therefore the question became irrelevant. However, this is anecdotal and cannot be utilised in the research, in future the answers to this question should be adapted to allow for this option

5.7 Practical Applications

The training characteristics of NZ players in this study reported tennis training hours at U12 that were largely in alignment with intervention studies using similar age cohorts, although it should be noted that these studies used all-male samples. At U14 tennis training volumes of elite players were in line or close to guidelines suggested by other National federations, nevertheless overall mean values of participants and that of sub-elite players was noticeably below the recommended guidelines. This was not the case for physical training and total training volumes in any of the groups in this cohort. Therefore, it could be recommended that when designing programme for elite players of this age, focus should be on creating time for physical training or allowing a more integrated approach for those who are time poor.

Additionally, based on the data around participation in other sports, it cannot be assumed that players will acquire a significant amount of their athletic development from that training. Despite high levels of participation in other sports at U12, for the majority the volume of that type of training is not high enough to bring them closer to the recommended amount of time dedicated to physical development. As expected, more players appear to have specialised at U14 and this is particularly prevalent among female players, at which point their athletic development is solely dependent on a holistic tennis programme. It would be beneficial for coaches to be mindful of this when preparing programmes and it may be necessary to work with the tennis coach to ensure the athlete receives sufficient training stimuli in all required areas.

5.8 Conclusion

In conclusion, this data obtained in this study agrees with the earlier hypothesis that U12 and U14 NZ players have lower training volumes and participation in physical training than is suggested for elite player development of this age. This study identified a possible weakness in the current practice of players and/or coaches in this country. The significance of how these lower training volumes impact on players achieving their physical potential or ultimately the progression of their tennis careers is not clearly understood. To gain a better understanding of this topic, further research is required that follows players longitudinally or accurately collating historical training information from current top players.

Chapter 6 – A case study analysis of the longitudinal physical development of elite New Zealand junior players with different levels of National federation support

6.1 Preface

The previous chapters analysed data on the training and physical characteristics of elite junior tennis players both internationally and in NZ. In doing so, it was possible to identify key physical attributes and trends within the different age groups which influence tennis performance and highlight a notable difference between the training volumes. The impact of how this variation in training volumes influences a player's physical development longitudinally has not been investigated. This chapter sought to gain further insight into player longitudinal development by analysing the data of 12 players who were selected into a talent ID programme at the age of 12 years. Within this group, there were players who received full coaching support from the National federation, partial support and no support, which indicates players followed very different developmental pathways.

6.2 Introduction

Worldwide, tennis governing bodies, and their respective coaches, have the difficult job of identifying young talented players who subsequently receive funding or support to optimise their development with the aim to progress them toward the international stage and a professional career. Regression analysis of ranking and results provides some information about what a player who is "on track" might look like based on historical statistical probabilities (Brouwers et al., 2012, Reid et al., 2009a, Reid et al., 2007b). The rest of the identification process is largely dependent on understanding potential tennis and physical development. Additionally, consideration is given to impact the largely immeasurable or unquantifiable impact that a player's psychological attributes may play (Bane et al., 2016, Bane et al., 2014, Reid et al., 2007b). The presence of the RAE and selection of players into talent development programmes with more advanced skeletal maturation over their younger counterparts is well-documented (Myburgh et al., 2016a, Myburgh et al., 2016b, Ulbricht et al., 2015b). Other sports, such as ice hockey, rugby union and football, have shown that later-maturing athletes who are just behind their more advanced peers during early adolescence are often overlooked for selection into teams or individual funding spots (Cobley et al., 2014). As all adolescents will eventually mature, it is theorised there is the risk that later-maturing players will "catch up" at least in terms of anthropometric measures and physical prowess, but having not been provided the coaching or support at an earlier age they do not maximise their potential which initially may have exceeded that of early maturer's (Cobley et al., 2014). In soccer, for example, longitudinal research has repeatedly found the trend of late maturing players being progressively underrepresented with age throughout adolescence which may be reflective of selective retention and/or exclusion in youth soccer (Valente-dos-Santos et al., 2012b, Philippaerts et al., 2006, Malina et al., 2000). Similar research in ice hockey found players of all stages of maturation, equally represented at age 11-12 years, but systematic exclusion (self, coach, combination, injury) of late-maturing boys with time. It appears with age and perhaps the increasing physicality of the sport, the associated superior body size, muscular strength and power of early and "on time" maturer's allows them dominate (Lariviere and Lafond, 1986). Although statistically the benefits of advanced skeletal age and maturation may be more apparent from an earlier age in tennis, whether these advantages persist post puberty has not been investigated (Myburgh et al., 2016b, Myburgh et al., 2016a). As the end goal for any player, coach or federation is success at professional level, understanding what part maturation plays on performance during adolescence and its significance to transitioning to professional sport, is just one part of being able to guide and estimate an athlete's future development. This is an area that has not been investigated in tennis, or necessarily proven in other individual sports. It further supports the need to track the development of players longitudinally, as the instability of physical and anthropometric factors during adolescence makes it difficult to predict the future development of a player (Cobley et al., 2014).

Limited empirical evidence exists following the longitudinal training practices of junior tennis players to enable understanding of the impact physical training has on the development of a players' physicality, subsequent progression of their junior careers, and eventual transition into senior tennis. In this regard, to date only one study has reported the overall physical development of junior tennis players longitudinally (Kramer et al., 2016a). Upper and lower body power, speed and agility of 196 players were assessed annually for three years, alongside anthropometric data to look at the impact of growth and maturation. Previous research found higher ranked girls scored better at U14 in lower body power, speed and agility and maintained this through to U16 level (Kramer et al., 2016a). In contrast, boys scores in these four components did not explain variation in ranking (Kramer et al., 2016a). The authors speculated that this could be due to the relative homogeneity of fitness level of male players in this population (Dutch National top 60) in comparison to the greater variation in females of the same age, enabling physical fitness to be more likely to be a predictor of playing level for girls. In this sample of players attending National Identification camp, both boys and girls improved across all four variables with age, however the relationship between these improvements and the type and volume of training the player completed was not explored. The Dutch talent development programme works on a pyramid basis, meaning more players are selected at age 13 than at 15 or 16 years of age (Kramer et al., 2016b). Data from this study cannot explain is the part that physical ability played in the continued selection or deselection of those at U16. This study did not identify or discuss if there was any movement of players between the high ranked (males– Top 10, female – Top 7) and lower ranked groups (males –11-60, females – 8-41) during this time and if this was influenced in any way by physical change or maturation.

Similarly, regarding using rankings in combination with physical ability as marker of future success, only one study has reported the longitudinal progression of careers of 83 of the top European juniors that were assessed at age 12-13 years (Unierzyski, 2002). The authors compared two groups; Group 1 were "young champions" (Top 5 European rankings or equivalent) yet never made it past an ATP ranking of 250 and Group 2 ranked below the top 15 aged 12 but eventually became the "world's best players" at senior level aged 19-21 years (Unierzyski, 2002). Significant differences in training frequencies and volumes were noted between the groups. On average, Group 2 practiced tennis 10 hours per week , which was 2.5 hours less than Group 1, and completed 2 hours more physical training than the mean (4-6 hours) (Unierzyski, 2002). It was suggested that advanced maturation and tennis experience were the main factors leading to early success of Group 1 players at U14 level, which this did not necessarily translate to senior success. Although the players' rankings were followed over 7 years, information regarding their training and assessment of their physical ability was only gathered at age 12-13 years and not reassessed, therefore what happened between 12-19 years old is not accounted for. Subsequently the relevance of the players early training habits and physical prowess is unknown, further research is needed to isolate which of the multiple factors investigated were responsible for the future success of Group 2 players.

Whilst the Kramer et al. study (2016) noted trajectories of specific physical characteristics and Unierzyski (2002)analysed training frequencies, neither looked at both together as factors which may be interlinked. Therefore, the aim of this study was to determine the trajectories of junior tennis players identified as "talented" at the age of 12 who followed different development pathways. This could be an important first step to taking a deeper look at what S&C practitioners are do regarding the physical development of young tennis players.

6.3 Methods

Twelve players who attended National Talent ID camp for Tennis NZ across a minimum of 3 years consecutively between 2014-2018 were analysed. As a minimum, all players selected attended camp during their 12th, 13th and 14th birth year. Anthropometric and physical fitness testing was carried out each year as part of the camp and all players agreed to their data being used anonymously for the purpose of this research. The testing battery used was the same as described in Chapter 4, with the addition of the Yo-Yo Intermittent Recovery Test (Level 1) as a measure of cardiovascular endurance (Krustrup et al., 2003). This test consists of repeated 2x20ms run back and forth between the starting, turning and finishing line, completed in alignment with protocol verbally dictated on the audio file with speed progressively increasing. Participants have 10s to rest between each run. The test ends when the participant fails to reach the finishing line twice and the distance covered represents the final score. In this study participants only completed the test once, but previous studies have a reported good test-retest reliability with CV of 4.9% reported by Krustrup et al. (2003) and excellent ICC's of 0.82-0.94 by (Deprez et al., 2015)

In addition, six of the 12 participants were chosen for more in-depth case study analysis. This required each player to complete an online questionnaire to provide a full training history for the 4-year time period (See Appendix H).

6.3.1 Subjects

All participants were junior tennis players nationally ranked in the top 10 for their birth year during the first testing session (12th birth year). Six males and 6 females were selected, and 3 from each gender were selected for analysis in this study based on their known funding and support history across 4 years.

6.3.2 Procedures

The three case study players from each gender were categorised as the following: "Fully supported athlete", "Partially supported athlete" and "Unsupported Athlete". A description of these training support categories is detailed in Table 6.1. All players and their parents consented to the anonymous use of their data and completed the questionnaire online.

6.4 Statistics

Data from the wider sample was collated in an Excel spreadsheet across 4 years and used to calculate mean and standard deviations. To calculate how far the case study players were from the means of the wider sample size, z-scores were calculated. The z-score was calculated by subtracting the mean score from the individual score and dividing by the standard deviation. To allow easier interpretation all z-scores used to format athletic profile graphs were made positive, so that a wider circle represented better performance all round.

Table 6.1 Basic description of different player support levels by National Federation

	Programme support	Day to day environment support
Fully Supported Athlete	Player continued to meet performance criteria across the 4 years, therefore entitled to receive full coaching and travel support	Provided with S&C and tennis coach for daily training and travel to tournaments
Partially Supported Athlete	Player initially met performance criteria and at some point, in the four years dropped below criteria. OR player lived outside of national programme city and chose to receive remote support or follow their own programme.	Provided with remote S&C programming completed either under supervision of parent of local coach (players choice). Continue to train with private tennis coach. Provided with international tour opportunities with travelling coach and S&C whilst making criteria.
Unsupported Athlete	Player did meet performance criteria and therefore not entitled to support from national federation.	No coaching support

6.5 Results

Anthropometric data of the female players (see Table 6.2) showed that player 2 and 3 could be classed as early maturer's (PHV earlier than one year prior to average – 12 years old) and the remaining 4 to be on-time (within 1 year of average) (Malina et al., 2015). Player 2 was the tallest and heaviest of the group and remained so throughout. High levels of RAE were present in this sample, with 100% of the players born in the first half of the year, with a 50:50 split between Q1 and Q2.

Data of the male players showed only Player 1 to be an early maturer, who had advanced height (10cm greater than the group mean) and weight at age 12 in comparison to his peers. This was maintained through to the age 14. The remaining players could be classified as "on-time" maturer's and player 6 ultimately overtook Player 1 in height age 15. Most players saw most significant weight gain between the age of 13 and 14 years (9.2 ± 7.4 kg), which for many was the year they went through PHV.

Table 6.2 Anthropometric and maturation characteristics of Female players followed across 3-4 years.

	Player No.	RAE	National Ranking	Birth year	Height (cm)	Weight (kg)	Time to/ from PHV (years)
FEMALE PLAYERS	1	Q1	1	12	167.7	54.6	0.4
			1	13	169.5	59.6	2
			1	14	170.3	61.4	2.4
			1	15	171.2	68.0	3.8
	2	Q2	2	12	169.5	55.4	1.2
			2	13	174.4	65.2	2.2
			2	14	176.5	74.2	3.2
			1	15	178.0	79.9	3.5
	3	Q2	3	12	164.0	53.0	1.6
			3	13	164.4	56.3	2.3
			9	14	165.2	57.4	3.1
			8	15	165.4	60.2	4.5
	4	Q2	8	12	161.7	47.5	0.5
			7	13	162.7	49.1	1
			2	14	167.7	57.6	2.3
	5	Q1	1	12	153.4	49.2	0.4
			1	13	161.3	56.1	1.1
			1	14	165.6	62.9	2.4
	6	Q1	1	12	158.6	50.3	0.9
			1	13	165.4	61.2	1.7
			2	14	167.8	68.3	2.2

Table 6.3 Anthropometric and maturation characteristics of Male players followed across 3-4 years.

	Player No.	RAE	National Ranking	Birth year	Height (cm)	Weight (kg)	Time to/ from PHV (years)
MALE PLAYERS	1	Q2	1	12	164.1	51.5	-0.2
			1	13	170.5	58.2	0.5
			1	14	179.2	69.2	2.3
			1	15	182.1	72.4	3.2
	2	Q2	2	12	156.3	47.8	-0.9
			1	13	167.3	56.1	0.1
			2	14	170.2	60.1	0.6
			1	15	177.6	66.5	1.4
	3	Q4	7	12	153.1	43.7	-1.8
			2	13	162.1	49.5	-0.5
			6	14	168.8	55.6	0.5
			6	15	178.2	61.5	1.6
	4	Q3	1	12	151.5	51.2	-1.2
			1	13	156.3	48.2	0.2
			2	14	164.5	59.3	0.9
	5	Q1	2	12	149.9	50.3	-1.5
			2	13	157.4	55.1	-0.5
			1	14	159.5	55.2	0
	6	Q4	3	12	154.0	40.3	-1.6
			4	13	159.0	43.1	-1
			10	14	174.9	66.6	0.6
			3	15	183.0	72.0	1.8

6.5.1 1st Physical Assessment - Females

The data in Table 6.4 for the 12th birth year highlights the differences between the three case study players (at the time nationally ranked 1, 2 and 3) and the average scores of a wider sample. All three players score above the average in speed and grip strength, while each player had their individual weaknesses where they scored below average. Individual weaknesses for Player 1 (forehand and backhand medicine ball throws), Player 2 (CMJ, SJ and grip strength) and Player 3 (forehand and backhand agility, CMJ and SJ, forehand and backhand medicine ball throws and Yo-Yo Distance).

Table 6.4 Mean physical fitness scores of all female players attending Tennis NZ national and regional camps between 2014-2018 and the z-scores of the 3-case study players

	Age/ Player Number	5m	10m	20m	FHAG	BHAG	CMJ	SJ	GSND	GSD	FHMB	BHMB	OHMB	Yo-yo (m)
Mean ± SD	12th Birth Year (n=48)	1.22 ± 0.08	2.11 ± 0.11	3.75 ± 0.19	2.51 ± 0.15	2.62 ± 0.15	28.75 ± 4.51	24.71 ± 4.31	23.96 ± 5.08	27.55 ± 5.68	9.98 ± 1.30	9.70 ± 1.37	7.96 ± 1.36	874 ± 298
Z-scores	Player 1	-0.83	-0.57	-0.75	-0.61	-1.24	0.65	-0.18	0.20	0.11	-0.10	-0.44	0.54	0.05
	Player 2	-1.1	-1.11	-1.50	-1.42	-1.3	-0.92	-0.54	-0.26	0.54	2.32	1.31	0.76	0.51
	Player 3	-0.57	-0.75	-1.01	0.44	0.73	1.90	-1.19	0.22	0.22	-0.52	0.50	0.54	-0.98
Mean ± SD	13th Birth Year (n=47)	1.18 ± 0.07	2.04 ± 0.10	3.60 ± 0.16	2.46 ± 0.13	2.54 ± 0.13	29.90 ± 4.05	26.16 ± 4.90	27.35 ± 5.47	31.55 ± 5.47	11.09 ± 1.47	10.53 ± 1.52	8.98 ± 1.59	1040 ± 368
Z-scores	Player 1	0.52	0.51	0.08	-0.12	-0.88	1.75	1.07	0.92	0.94	0.35	1.03	0.26	-0.19
	Player 2	-1.16	-0.15	-1.44	-1.82	-1.76	-0.47	-0.28	-3.25	2.79	2.04	2.15	0.96	058
	Player 3	0.04	0.11	-0.22	0.57	0.24	-1.48	0.58	-1.28	-0.74	-0.81	-0.28	0.45	-0.99
Mean ± SD	14th Birth Year (n=51)	1.15 ± 0.05	2.00 ± 0.06	3.54 ± 0.12	2.43 ± 0.12	2.47 ± 0.11	30.70 ± 3.89	26.88 ± 3.97	28.91 ± 5.58	33.74 ± 6.32	11.27 ± 1.49	10.72 ± 1.61	9.60 ±1.54	995 ±342
Z-scores	Player 1	-0.39	-0.30	-0.14	-0.33	-0.49	1.11	0.41	1.23	1.11	-0.18	0.61	-0.39	0.13
	Player 2	0.63	<0.01	-0.82	-1.67	-1.62	0.80	-0.68	2.40	2.73	2.30	3.46	1.81	-0.08
	Player 3	1.24	0.93	0.11	-0.50	0.36	0.10	-0.37	-0.07	0.12	-0.18	0.11	0.19	0.25
Mean ± SD	15th Birth Year (n=34)	1.15 ± 0.06	2.00 ± 0.06	3.53 ± 0.22	2.43 ± 0.12	2.54 ± 0.16	29.87 ± 5.24	25.68 ±4.51	30.67 ± 6.91	36.08 ± 9.96	11.44 ± 1.41	11.00 ±1.73	9.22 ±1.43	984 ±451
Z- Scores	Player 1	-0.80	-0.03	-0.30	-0.18	-0.05	1.65	1.31	0.65	0.92	1.04	1.21	0.90	0.01
	Player 2	0.28	0.07	0.07	-1.39	-0.43	-0.57	-1.0	1.92	1.48	2.80	2.13	1.59	0.26
	Player 3	-0.80	-1.21	-1.28	-0.34	-1.23	0.75	0.34	0.80	0.46	0.28	0.23	0.26	0.36

6.5.2 Longitudinal Development

Using z-scores to illustrate change in comparison to age-matched means, at age 15 Player 1 sits above average in all components. Relative to the mean, player 1's advantage in speed and agility is less at age 15 than at age 12 (e.g., z scores of -1.2 age 12 vs -0.05 age 15 in backhand agility, -0.75 vs -0.30 in 20m). Player 1 achieved significantly greater in measures of power (e.g., -1.1 vs 1.0 in forehand medicine ball throw, 0.66 vs 1.60 in CMJ).

Player 2 maintained the same weaknesses in lower body power (CMJ -0.92 vs -0.57, squat jump-0.54 vs -1.04), in addition to a drop off short sprint speed, 5m (-1.1 vs 0.28) and 10m (-1.1 vs –0.06). Player 2 scored highest in upper body power by a substantial amount, but z-scores reflected that she maintained a similar advantage across the 4-years rather than any rapid improvement in forehand medicine ball throw (2.32 vs 2.80). Player 2 made significant progress in backhand medicine ball throw (1.31 vs 2.13) and overhead medicine ball throw (0.76 vs 1.59).

Player 3 also scored above average at age 15, with superior speed and agility scores to Player 1, but inferior upper and lower body power scores. In comparison to age 12, Player 3 has made the most improvement across the board to become a more well-rounded athlete, as evident in the player profile shown in Figure 6.1.

Figure 6.3 (A-D) depicts the trajectories of some of 4 key physical components discussed above and highlights both individual variation and non-linear nature of their athletic development across the 4-year period.

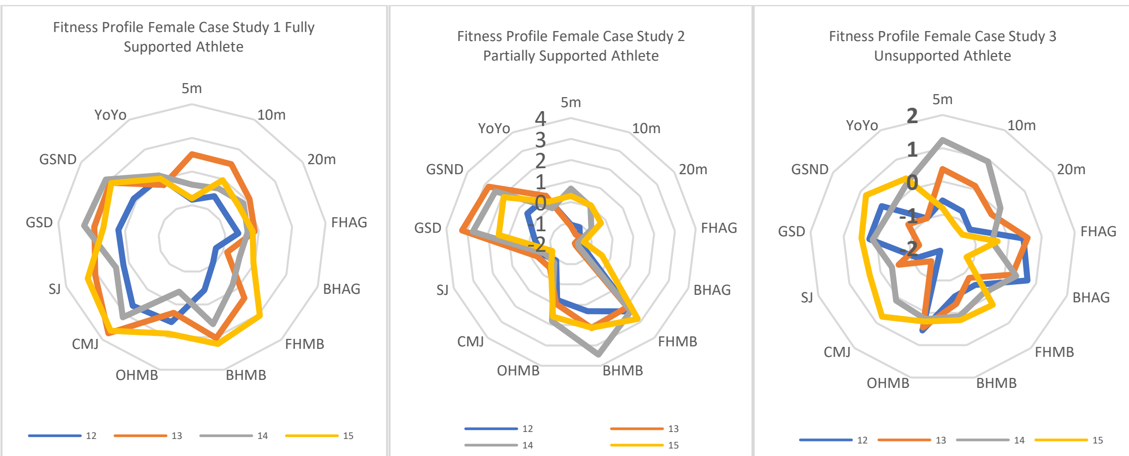


Figure 6.1 Physical profiles of 3 female case study players.

Abbreviations: 5,10 and 20m – Sprints, FHAG: Forehand Agility, BHAG: Backhand Agility, FHMB: Forehand Medicine Ball throw, BHMB: Backhand Medicine Ball throw, OHMB: Overhead Medicine Ball throw, CMJ: Countermovement Jump, SJ: Squat Jump, GSD: Grip strength dominant, GSND: Grip strength non-dominant, Yo-Yo: Yo-Yo Intermittent Endurance

6.5.3 1st Physical Assessment – Males

As the only early maturer in the group it is evident from the z-scores that Player 1 outperforms both the case study players and the age-matched mean in most components except for the jump tests (See Table 6.5). Player 1 excelled most in backhand agility (-2.22), overhead medicine ball throw (2.90) and grip strength (non-dominant side) (2.16). Player 2 scored just above average in all components except for the 5m sprint. Player 3 performed close to the mean in most components sitting just above or below the mean (0.06-0.548), apart from upper body power where he was significantly above average (forehand medicine ball throw:2.05, backhand medicine ball throw:1.49, overhead medicine ball throw: 1.44).

Table 6.5 Fitness characteristics of all male players attending Tennis NZ national and regional camps and the 3-case study players

	Age/ Player Number	5m	10m	20m	FHAG	BHAG	CMJ	SJ	GSND	GSD	FHMB	BHMB	OHMB	Yo-Yo (m)
Mean ± SD	12th Birth Year (n=67)	1.21 ± 0.09	2.08 ± 0.12	3.70 ± 0.23	2.48 ± 0.14	2.59 ± 0.13	29.60 ± 4.60	25.89 ± 4.95	20.93 ± 4.5	25.55 ± 5.42	9.26 ± 1.64	10.06 ± 1.77	7.52 ± 1.20	1045 ± 383
Z-scores	Player 1	-1.68	-1.78	-1.92	-2.23	-1.20	-0.03	-0.16	2.16	1.50	1.26	1.49	2.90	0.26
	Player 2	0.06	0.10	-0.53	-1.08	-0.90	0.15	0.67	0.72	0.53	0.42	0.57	0.11	0.03
	Player 3	0.52	0.47	0.39	-0.6	0.02	0.07	0.55	-0.29	0.06	2.05	1.49	1.44	0.03
Mean ± SD	13th Birth Year (n=74)	1.17 ± 0.08	2.04 ± 0.13	3.61 ± 0.25	2.44 ± 0.14	2.53 ± 0.15	31.07 ± 6.17	27.22 ±5.97	25.69 ± 5.19	30.27 ± 544	10.50 ± 1.53	11.33 ± 1.54	8.50 ±1.36	1263 ± 488
Z-scores	Player 1	-0.69	-0.59	-0.92	-0.53	-1.08	-0.13	0.20	1.50	1.44	0.89	0.98	1.47	0.20
	Player 2	0.31	-0.12	-0.30	-1.02	-0.75	-0.04	0.46	0.20	0.28	1.02	1.28	1.03	0.20
	Player 3	-1.07	-0.43	-0.30	-1.51	-1.21	0.00	0.06	0.68	1.05	1.41	1.64	2.90	-0.02
Mean ± SD	14th Birth Year (n=53)	1.13 ± 0.06	1.97 ± 0.10	3.48 ± 0.17	2.36 ± 0.12	2.42 ± 0.12	32.97 ±4.95	28.83 ± 3.94	29.04 ± 6.01	33.84 ±6.88	11.89 ± 2.04	12.69 ±1.71	10.07 ± 2.09	1502 ± 568
Z-scores	Player 1	-1.21	-1.56	-1,75	-1.36	-1.37	0.8	0.71	3.68	3.44	2.22	2.07	2.21	0.65
	Player 2	-0.95	-0.98	-1.20	-1.65	-1.54	0.25	1.01	1.75	2.02	1.61	1.44	3.05	0.39
	Player 3	-0.12	-0.21	-0.17	0.02	-0.39	-0.38	-0.90	0.74	-0.15	1.45	1.09	1.16	-0.20
Mean ± SD	15th Birth Year (n=40)	1.09 ±0.06	1.89 ±0.09	3.32 ± 0.17	2.28 ±0.09	2.34 ±0.09	37.25 ± 5.42	31.43 ± 4.21	35.56 ± 8.72	43.75 ± 10.42	14.27 ± 2.08	14.91 ± 1.82	11.78 ±2.24	1939 ± 522
Z- Scores	Player 1	-0.95	-0.90	-0.85	-0.23	-0.23	0.56	0.33	0.85	1.05	0.93	1.32	0.99	0.30
	Player 2	0.34	-0.11	-0.82	-1.02	-0.80	-0.20	0.45	2.66	2.34	1.41	1.48	1.74	0.17
	Player 3	-0.96	-0.79	-0.42	-1.54	-1.87	-0.02	0.80	1.69	0.78	2.58	2.11	1.39	-0.51

Key: 5m= 5m sprint, 10m=10m sprint, 20m=20m sprint, FHAG=Forehand Agility Test, BHAG=Backhand Agility Test, CMJ=Countermovement Jump SJ=Squat Jump, GSND= Grip Strength Non-Dominant side, GSD=Grip strength Dominant side, FHMB=Forehand Medicine Ball Throw, BHMB=Backhand Medicine Ball Throw, OHMB=Overhead Medicine Ball Throw, Yo-Yo=Yo-Yo Intermittent Recovery Test (level 1).

6.5.4 Longitudinal Development

At age 15, Player 1 scored above average in all components, including in his two weaker areas of CMJ and SJ. However, the physical advantage seen age 12 is substantially less at age 15, in fact most of his z-scores for his 15th birth year were ~50% of those seen at age 14 (See Table 6.5). At age 15 Player 2's athletic profile remained largely unchanged from age 12 (see Figure 6.2). Player 2 performed above average in all areas except for 5m and countermovement jump (-0.20). Performance in countermovement jump across the 4-years was variable. Player 2 made notable progress in upper body power and strength (forehand medicine ball throw: 0.42 vs 1.40, backhand medicine ball throw:0.57 vs 1.48, overhead medicine ball throw: 0.11 vs 1.73, grip strength dominant side :0.53 vs 2.64, non-dominant side: 0.72 vs 2.34).

Player 3 age 12 scored below average in 4/5 speed and agility tests, but by age 15 had made significant progress in this area and scored significantly above the mean in 5/5 tests. He maintained above average scores for upper body power and grip strength throughout the 4 years. Conversely, throughout the four years, Player 3's countermovement jump (-0.02) and endurance (-0.51) deteriorated to below the average for his age.

Some of the differences and commonalities in the developmental trajectories of four the key components relating to tennis performance (5m sprint, Forehand agility, CMJ and forehand medicine ball) can be observed in Fig 6.3 (E-H).

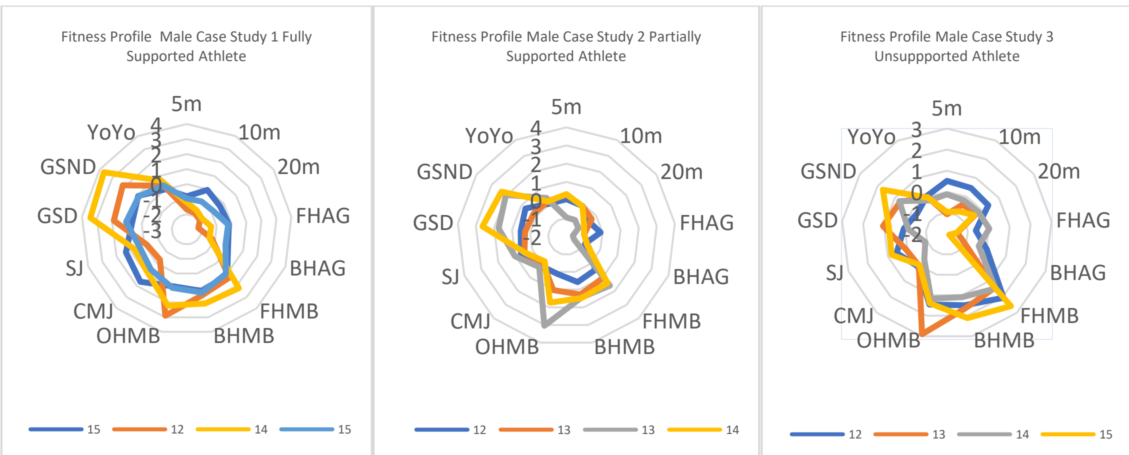


Figure 6.2 Physical profiles of 3 male case study players

Abbreviations: 5,10 and 20m: Sprints, FHAG: Forehand Agility, BHAG: Backhand Agility, FHMB: Forehand Medicine Ball throw, BHMB: Backhand Medicine Ball throw, OHMB: Overhead Medicine Ball throw, CMJ: Countermovement Jump, SJ: Squat Jump, GSD: Grip strength dominant, GSND: Grip strength non-dominant, Yo-Yo: Yo-Yo Intermittent Endurance

6.5.5 Training History and Characteristics of Case Study Players

Table 6.6 and Table 6.7 describes training frequency, volumes, type and structure of training obtained from the self-report questionnaire for female and male players, respectively. Both fully supported players completed significantly higher training volumes from the age of 12 onwards (Table 6.6). In the female case studies, the players 2 and 3 consistently reported lower training volumes at all ages and only player 2 in the male case studies reported similar training volumes at age 15 but not prior. Both female and male Player 3's reported an incremental increase in tennis training volume until age 14, followed by a decline at age 15, by which point both players had dropped out of the top 5 for their birth year (see Table 6.1).

In terms of S&C training, all three female players participated in the same volume of training age 12, but only player 1 followed a structured programme from an S&C coach. Whereas the training volume of Player 1 increased gradually across the 4 years, player 2 only increased to 2-3 hours age 15 equating to 50% of the volume of player 1. Player 3 consistently completed 2-3 hours per week from age 13-15. However, Player 2 continued to play other sports on a weekly basis between the age of 12-14, but players 1 and 3 had specialized by the age of 12.

Player 1 completed private coaching with a S&C coach from age 12-15 years in a gym environment. Player 2 received remote S&C programming from age 13-14 years which she completed at home on her own, before joining group training sessions that followed a generic training programme at age 15. At age 12, Player 3 participated in fitness training run by her tennis coach, before joining a group S&C training specifically designed for young tennis players aged 13-15.

Similarly, for the male case study players, the fully supported player (Player 1) started and maintained higher S&C volumes across the 4-years. Player 1 initially followed a programme set by an S&C coach and was supervised by a parent, before transitioning to full time training with an S&C coach at age 13. Player 2 received remote programming from a S&C coach from the age of 13 and chose to complete his training without supervision entering the gym environment at age 14. Player 3 participated in S&C training in private sessions at lower volumes than Players 1 and 2 throughout the 4 years.

Table 6.6 Training characteristics of Female case study players

	12th birth year			13th birth year			14th birth year			15th birth year		
Player	1	2	3	1	2	3	1	2	3	1	2	3
Tennis training hours per week	12+	4-6	8-10	8-10	6-8	6-8	10-12	8-10	6-8	12+	8-10	6-8
Fitness training hours per week	1-2	1-2	1-2	2-3	1-2	2-3	3-4	1-2	2-3	5-6	2-3	2-3
International tournaments per year	6 (U14)	6 (U14)	1 (U14)	8 (U18)	0 (U18)	0 (U18)	14 (U18)	5 (U18)	2 (U18)	15 (U18)	7 (U18)	0 (U18)
S&C location	Gym	Home	Home	Gym	Home	Gym	Gym	Home	Gym	Gym	Gym	Gym
S&C supervision	Group session with S&C coach	Private session with tennis coach	Self-led	Group session with S&C coach	Self-led	Group session with S&C coach	Private session with S&C coach	Self-led	Group session with S&C coach	Private session with S&C coach	Group session with S&C coach	Group session with S&C coach
Structured programme	Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Participation in other sports	None	Yes – 5hrs	None	None	Yes -3hrs	None	None	Yes-2hrs	None	None	None	None

Table 6.7 Training characteristics of male case study players

	12th Birth Year			13th Birth Year			14th Birth Year			15th Birth Year		
	1	2	3	1	2	3	1	2	3	1	2	3
Tennis training hours per week	12+	6-8	8-10	12+	8-10	6-8	14+	10-12	6-8	14+	14+	6-8
Fitness training hours per week	5-6	1-2	1-2	5-6	1-2	2-3	6+	3-4	2-3	6+	5-6	3-4
International tournaments per year	6 (U14) 2 (U18)	2 (U14)	8 (U14) 2 (U18)	4(U18)	0 (U18)	0 (U18)	5 (U18)	0 (U18)	0 (U18)	15 (U18)	6 (U18)	3 (U18)
S&C location	Gym	Home	Gym	Gym	Home	Gym	Gym	Gym	Gym	Gym	Gym	Gym
S&C supervision	With parent	Self- led	Private session with S&C coach	Private session with S&C coach	Self-led	Private session with S&C coach	Private session with S&C coach	Self- led	Private session with S&C coach	Private session with S&C coach	Self-led	Private session with S&C coach
Structured programme	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Participation in other sports	Yes – 3hours running	None	None	Yes – 2hrs running	None	None	None	None	Yes- 2 hours	None	None	None

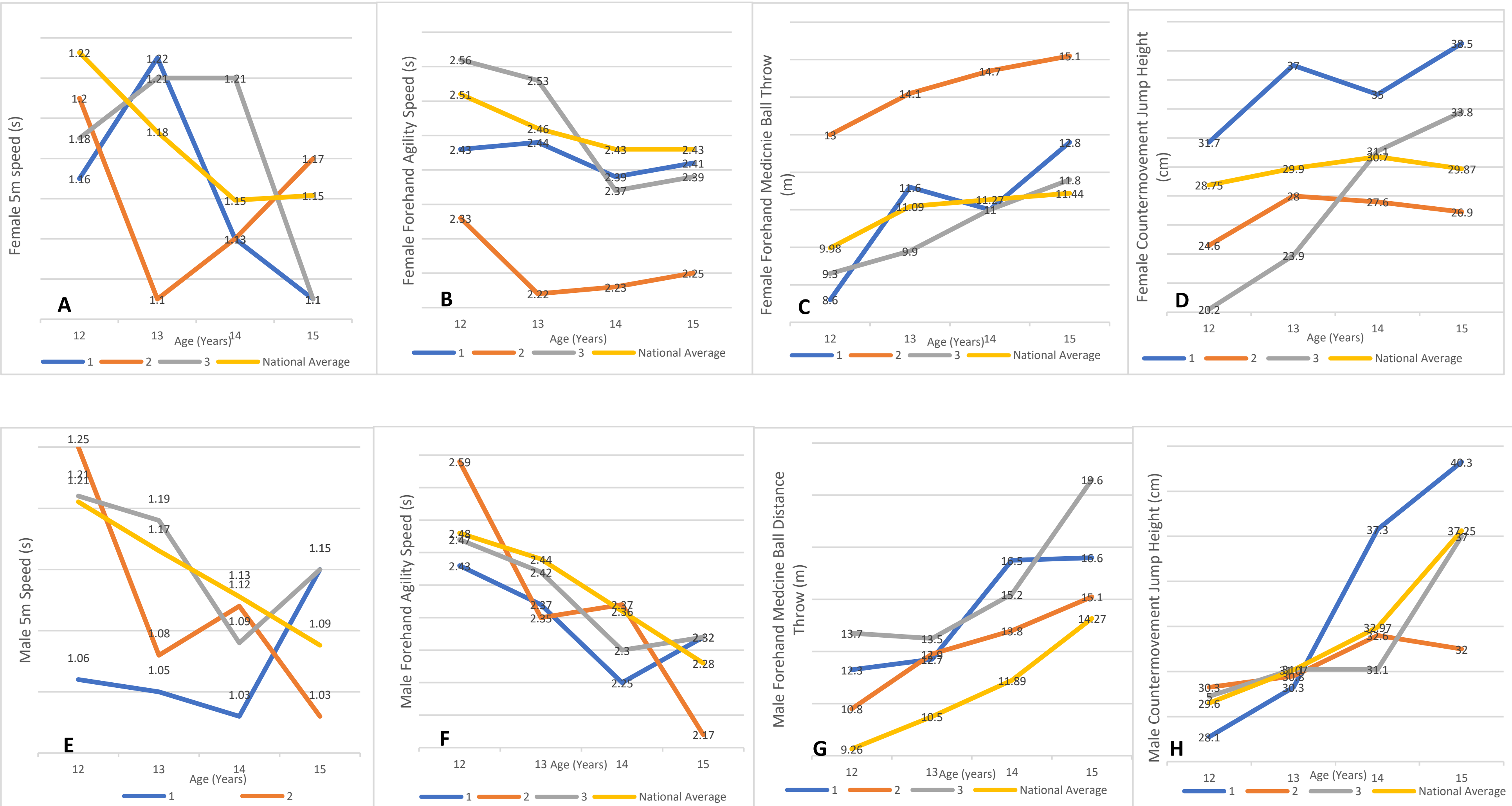


Figure 6.3 Longitudinal trends in key fitness characteristics – A: Female 5m sprint, B: Female Forehand Agility, C: Female Medicine Ball Throw, D: Female Countermovement Jump, E: Male 5m sprint, F: Male Forehand Agility, G: Male Forehand Medicine Ball , H: Male Countermovement Jump

6.6 Discussion

This study explored the longitudinal development of a select sample of National-level junior tennis players with different exposures to physical training. This analysis revealed some key commonalities and differences between players. Within both genders, there was evidence, that the players with the highest volume of S&C at age 12 or prior to the first assessment had the most well-rounded athletic profiles and had the highest tennis training volume. As development of a youth athletes' athletic foundation has been shown to be a combination of previous exposure to sport and movement, it is difficult to ascertain what part of their early training environment (tennis training, structured S&C, other sports) contributed most to their physical superiority age 12(Myer et al., 2013). The results demonstrated that both fully supported players who remained in structured S&C throughout the 4-years ultimately maintained above average scores at age 15. Their scores did not reflect continuous linear improvement, rather athletic profiles without obvious deficits, despite increased time spent travelling internationally for tournaments in comparison to their peers and therefore less available training time (See Table 6.6 and Table 6.7). The two players who were partially supported and therefore received remote S&C programming without supervision, saw improvement with age in areas they excelled in at age 12, but saw no significant change or decrement in performance in their areas of weakness. Both players entered a gym training environment at a later stage and were slower to increase S&C weekly training hours with age. The two unsupported players played fewer tournaments and completed lower volumes of tennis training, while both undertook supervised S&C for the majority of the 4-year period. This consistency appeared to provide these two players ample opportunity to improve their overall athletic ability, presenting much improved athletic profile at the end of the 4-years.

In comparison with existing literature, the only other longitudinal tennis study focused on development of 4 key physical characteristics: speed, agility, lower body and upper body power. The study by Kramer (2016) focused on a later stage of adolescence (14-16 years old) than the present study but found both genders to improve in these components with age in this time period. With a dearth of any other research to compare results to, the same components have been highlighted to note similarities or differences of the trajectories during the age bracket analysed in this study (12-15years old) (See Fig 6.3 A-H). These results of NZ players reflect slightly more variable trajectories, which are discussed below.

6.6.1 Female Players

The overall trend of NZ players reflect a sharp improvement during the 13th birth year, which for most is the year after PHV and the time most likely for females to go through Peak Weight Velocity

(PWV) (Lloyd and Oliver, 2012). The anthropometric data of the case studies appears to align with this, with most players gaining the greatest amount of weight between their 12th and 13th birth year testing (7.2 ± 3.4kg) (see Table 6.2). This is followed by a peak in speed during the 14th birth year, for most players after which it appears to plateau. Agility measures tracked in a similar fashion. This is largely in agreement with earlier research which has shown girls to make limited gains in speed across adolescence (Lloyd et al., 2013). Previous paediatric literature shows that initial changes in speed and agility in puberty can initially be correlated to stride length, indicating a natural improvement in these areas post PHV may be expected when limb length has increased (Rumpf et al., 2012). Concomitant improvements in ground reaction forces are not seen as a natural development and it is more likely that stride length improvements in adolescents are linked to improvements in force application (Oliver et al., 2013). All three case studies followed different trajectories in both measures. In speed, Player 1 showed linear improvement, Player 2 deteriorated sharply with age after the initial 13th birth year improvement and Player 3 appeared to worsen before getting better age 15. Likewise for the agility measures Player 1 and 3 followed the average trend of gradual improvement until age 14 before a plateau or minimal decrement, whereas Player 2 showed gradual decrement from age 13.

Combining this information with the trajectories of the scores in force production measures (jumping and throwing), Player 2 showed a decline in lower body force production (CMJ) in contrast to the more linear improvement of Players 1 and 3. It could be theorised that for this Player 2, the lack of improvement in force application may explain part of her lack of progress into later adolescence. By following a larger number of players adolescent training, it may be possible to identify how much certain training characteristics (frequency, type, volume, coaching supervision) contribute to the development of certain physical qualities.

6.6.2 Male Players

Previous research has shown that improvements in physical testing measures in adolescent males is strongly linked to pubertal development (Malina et al., 2005, Lloyd et al., 2011b). this is mediated by changes in hormone availability, in particular serum testosterone and growth hormone (Pearson et al., 2006). On average performance for male youth athletes in physical testing tends to improve with age from the age of 13-18 years old and the mean data for NZ players aligns with this (Pearson et al., 2006). The case studies used in this study highlight a different pattern. In terms of speed and agility, Players 1 and 3 initially showed superior speed and agility qualities to Player 2. Whilst Players 1 and 3 track positively until age 14, both see a decrease in performance in these tests at 15, whilst Player 2 tracks linearly to ultimately be the fastest of the three players. Player 2 starts as highest performing in CMJ and saw minimal improvement across the 4-years (<10%), whereas Players 1 and 3 improve with age and significantly outperform Player 2 at age 15 years. Lastly, in forehand medicine ball all three improve with age, but it is Player 3 (the latest maturer of the three) that achieves the most significant progress. It could have been expected with Player 2, that his improvement in speed would come with concomitant improvement in lower body power. As this or associated qualities (morphological change, pennation angle, tendon stiffness) largely explains change in power production in later adolescence (countermovement jump), (Oliver et al., 2013), however the opposite is true in this case. This brings in to question numerous factors that are not always accounted for in talent identification in tennis and other sports when comparing athletes (e.g., maturation and timing of PHV, genetics, timing of testing)(Malina et al., 2015, Pearson et al., 2006). It also reinforces that given the variation in this small sample, the unstable development of anthropometric and physical characteristics of youth athletes during adolescence impacts performance make using this type of data in one-off testing situation very unreliable (Cobley et al., 2014).

6.6.3 Limitations

The small number of the participants in this study is the main limitation to this study. The data has provided an original insight into the current landscape of elite player development in New Zealand, but not sufficient to drawing definitive conclusions. Although the apparent trends within the data align with similar trends seen in other sports (Cobley et al., 2014, Oliver et al., 2013), a repeat study with a larger cohort could identify if these are statistically significant trends in tennis. Lastly, some of qualitative data acquired in the questionnaire was dependent on the recall and memory of youth athletes which is subject to human error.

6.7 Practical Applications

This data highlights a perpetual problem for national sporting federations, that by selecting athletes based on physical ability at a young age may provide those individuals with opportunity they may not have otherwise received (e.g., financial support, coaching, training facility, competition) and likewise removing potential opportunity for those just missing out on selection. Given the variable trajectories of development during adolescence, what cannot be measured is which individual would ultimately have become the best if they were all afforded the same opportunities (Meylan et al., 2010, Pearson et al., 2006, Cobley et al., 2009, Cobley et al., 2014). In the case study examples used in this chapter, the fully supported athletes ultimately remained the highest ranked after 4-years and the unsupported athletes dropped down the rankings. Whether this is to do with physical talent presented on initial assessment or the opportunities provided to those selected and lack thereof to those not selected, cannot be quantified with any certainty. As with studies in other sports, many of the notable advantages held by individuals aged 12 are diminished at age 15, suggesting that a more even field is often created by the latter stages of puberty (Cobley et al., 2014, Kramer et al., 2016a, Kramer et al., 2021). For small federations such as in NZ, physical assessments in a talent ID setting, would deliver most value by providing the players and their coaches with information on athlete's current strength and weaknesses. The z-score radar graphs used in this study are a useful infographic to highlight these simply to the reader (Cobley et al., 2014).

6.8 Conclusion

In conclusion this study has demonstrated that longitudinally tracking progress of larger numbers of athletes, whilst recording their training volumes may begin to build a picture of what a successful training pathway looks like, rather than depending on guideline recommendations. Additionally, future studies can use the detailed longitudinal training history data of players who successfully turn professional. This would provide scope to use a retrospective approach to analyse the protective or detrimental effect of their junior training characteristics, regarding factors such as injury frequency and severity, career success and longevity. This is not to say a one-size fits all approach will be administered as a result, although eventually it can create a body of evidence more suited to providing information to enhance evidence-based practice.

Chapter 7 – The efficacy of the use of a modified Athletic Ability Assessment in junior tennis players

7.1 Preface

The development of fundamental movement skills (FMS) during early childhood and adolescence has been identified as a priority for formation of an essential athletic foundation needed for sport (Lloyd and Oliver, 2012). To date research has not yet evaluated how competency in these foundational athletic movements influence performance in the key physical fitness characteristics identified in Chapter 4, or in relation to tennis performance. Chapter 5 demonstrated that those with greater physical training volumes scored highest in these tests and generally had higher rankings. Furthermore, Chapter 6 provided the first indication that those following a structured formal S&C programme over several years had better performance outcomes (physical and tennis) than those who did not. Drawing on these findings, as FMS development is a key focus of youth S&C, it may be fair to assume that players with greater formal physical training experience have acquired better movement competency through this. It could therefore be hypothesised that these players would also score better on a movement screening and could be an important contributor to tennis performance. This has not been examined previously and we do not know if movement screens are capable or sensitive enough to assess this. To date there is little information about the use of movement screenings within tennis and particular in juniors, despite it being widely accepted as common practice amongst sport and health professionals (Kritz, 2012, Ransdell and Murray, 2016). This chapter therefore aimed to evaluate the efficacy of use movement screenings within junior tennis populations and investigate the relationship between screening scores with physical fitness and tennis performance.

7.2 Introduction

Paediatric S&C literature has established links between movement competency and overall health, well-being, physical activity and to a lesser extent performance (Lloyd and Oliver, 2012, Oliver et al., 2011). Consequently, movement screenings have been developed to provide a method of objectively assessing these skills (Cook et al., 2006, Cook, 2010, McKeown et al., 2014, Bishop et al., 2015, Kritz, 2012).

Multiple national and international governing bodies recommend their use as an assessment and monitoring tool for top players (Reid et al., 2003, Fernandez-Fernandez et al., 2014b), but this is not backed by evidence regarding the validity, reliability or effectiveness in tennis or how screening results relate to injury risk or performance. As tennis requires complex coordination of the kinetic chain, gaining an empirical understanding the relationship between movement quality and tennis performance will only enhance the athletic development of young tennis players. Presently, research regarding screening of tennis players is limited to musculoskeletal assessment carried out by medical professionals (Ellenbecker et al., 2015).

The merits and limitations of different movement screenings in previous research are discussed in Chapter 1, in this thesis the Athletic Ability Assessment (AAA) (McKeown and Ball, 2013) has been chosen as the method of FMS assessment. This study aimed to determine the validity and efficacy of a modified AAA as an ecologically valid screening tool in tennis. It did this by attempting to understand the relationship between performance in the fundamental movement tasks of the screening with performance in fitness or tennis skill tests, subsequently identifying whether competency in these tasks is one of the influential factors. The objective was to create a more detailed picture of an athlete's current strengths and weaknesses, guiding prescription of training, pertaining specifically the areas with most room for improvement. This information can potentially be combined with existing empirical evidence alluding to which physical characteristics have the most significant impact on performance during adolescence. Lastly, previous studies have found efficacy for use of movement screenings in providing insight to an athlete's competency in movement patterns S&C coaches anticipate loading (Howe and Bishop, 2022)). Subsequently, potentially allowing appropriate and safer prescription for the athlete's level of maturity and physical competency (Kritz, 2012). Likewise, this study aimed to identify the value of movement screenings in junior tennis populations through gaining understanding of the relationship between movement competency and tennis and physical fitness performance. The ultimate objective being to understand their role within the athletic development of junior tennis players.

7.3 Methods

7.3.1 Subjects

Participants for this study were recruited in two ways. The first group were volunteers who agreed to participate in an FMS training study. The study was advertised to coaches, players and parents in the region and all players (n=40) aged 10-15 years were invited to take part, regardless of playing level. It was however stipulated that tennis should be the participants "main" sport and that they participated in training at least three times per week. Additionally, participants had to be free of injury and illness which could impact their ability to complete the screening and subsequent testing. Players and parents were provided with an information sheet detailing the purpose and procedures of the study before taking part in the testing session. Group 2 consisted of elite players (n=17) (age group ranking <10) attending national camps during which the same screening and testing protocols took place at the start of the camp. These players consented to their data being used anonymously as part of this study. Auckland University of Technology Ethics Committee for Human Research approved the study (16/131), and an informed consent form was collected from a parent of each participant, as well an informed assent form from the participants, prior to data collection.

Biological age as defined by the Mirwald equation (Mirwald et al., 2002) was used to separate players into groups (pre-PHV and post-PHV).It is suggested that maturity offset can be estimated within an error of ± 1yr 95% of the time, with acceptable standard error (± 0.592 years) (Mirwald et al., 2002). Therefore, there is potential that the 7 players of the 40 whose biological age was calculated to be within the range -0.6 - +0.6 yrs to/from PHV, could have been placed in the wrong group and this is acknowledged as a limitation of the study.

Table 7.1 Descriptive statistics of all subjects

	Mean ± SD		
	Overall	Male (n=15)	Female (n=25)
Ranking	36.4 ± 71.8	63.7 ± 88.9	31.3 ± 64.4
Age (years)	12.9 ± 15	12.7 ± 1.5	13.1 ± 1.6
Height (cm)	154.5 ± 24.5	148.3 ± 38.3	159.1 ± 9.3
Weight (kg)	48.7 ± 12.2	47.8 ± 11.1	52.1 ± 12.2
Biological age (years ± PHV)	0.1 ± 1.8	-0.8 ±1.6	+1.1 ± 1.4

7.3.2 Procedures

A standardized 15-minute warm up was completed (See Chapter 4), consisting of a cardiovascular section designed to raise heart rate and elevate tissue temperature, dynamic stretches, light strength exercises and sport specific movement skills. A modified AAA was then carried out (Table 7.2). In line with current opinion on implementation of movement screening batteries, players received full verbal explanation of scoring criteria in addition to visual demonstration for each movement (Gamble, 2013, Frost et al., 2012). The players were provided with the opportunity to ask questions and permitted to have practice attempts to ensure understanding of task. This was also done to limit scope for future screenings to be influenced by the learning effect. The AAA was originally created to assess adult professional athletes (McKeown et al., 2014), but as this study focused on young players with limited S&C training experience, the protocol was adapted accordingly to be appropriate for players of both inferior size and level of conditioning. Chin-ups were part of the original protocol but could not take place on court so were removed for this study. These changes evolved from piloting the screening on non-participant players training under the primary researcher's guidance. Each movement was recorded on video camera for later analysis and followed the specifications of the modified protocol detailed in Table 7.2. The screening was scored by two independent raters who marked movements against the previously described template in Table 7.2, blinded to the scores of the other. Both raters had 5+ years' experience as qualified S&C coaches, with the second rater also a qualified physiotherapist.

The scoring criteria was also edited where required, when the number of complete repetitions was included as an independent section within the exercise score (Table 7.3). As some participants missed some tests at the start of the testing sessions due to school timings, two different total scores were used to assure there was no bias caused by the missing tests. "Total Percentage score" reflected score from only the completed tests by the individual, whereas "Total" reflected an individual total score out of all tests, even those not completed.

The same warm up and testing battery and procedures as described in Chapter 4 was completed after the screening. The same order was upheld; Anthropometry, grip strength, jumps, throws, change of direction speed, linear speed and Serve Velocity test.

Table 7.2 Modified AAA Protocol - Movement Screening

Exercise	Original protocol (McKeown et al., 2014)	Modifications
Overhead Squat	10kg Olympic Bar x 5 repetitions	Unloaded. 6 repetitions. 3 x reps recorded from each anterior and lateral view
Walking Lunge	20kg Olympic Bar x 10 steps	Unloaded. 10 steps. 5 reps each recorded from anterior and lateral view
Single Leg Squat off Box	5 x repetitions of each side	6 x repetitions. 3 x reps recorded from each anterior and lateral view
Single Leg Forward Hop	3 x repetitions of each side	No modifications.
Lateral Bound	3 x repetitions of each side	5 x repetitions of each side
Push ups	Minimum repetitions 20 reps (male) 12 reps (female)	Standardised to 10 repetitions
Chin Ups	Minimum repetitions 10 reps (male) 4 reps (female)	Not completed. Not possible on court or achievable for cohort of players
Prone Hold on Hands	2mins	No modifications
Lateral Hold on Hands	2mins	No modifications

Table 7.3 Modified AAA Scoring Criteria

Original Scoring Criteria (McKeown et al., 2014)				
	Assessment Points	3	2	1
Overhead Squat (OHS)	Trunk Control	Maintains bar overhead with appropriate shoulder/thoracic extension and trunk angle with no rotation	Bar over mid-foot but incorrect movement patterning	Excessive or inappropriate trunk inclination
	Hip/Knee/Ankle Alignment	Perfect alignment and control of hip/knee/ankle throughout every rep	Inconsistent form with some perfect reps OR minor misalignment on all repetitions	Unable to attain correct position
	Depth	Hip below knee (below parallel) while maintaining neutral spine for all repetitions	Depth beyond parallel for some but not all reps	Not able to achieve required depth for any reps
Walking Lunge (WL)	Knee/Ankle Alignment	Perfect alignment and control of hip/knee/ankle throughout every rep	Inconsistent form with some perfect reps OR minor misalignment on all repetitions	Unable to attain correct position
	Hip Control	Perfect alignment of hips throughout	Inconsistent form with some perfect reps OR minor loss of control on all reps	Excessive loss of control from neutral throughout the movement
	Trunk Control	Maintain neutral spine throughout. Not forward or side flexion/movement	Inconsistent form with some perfect reps OR minor loss of control in all reps	Forced lumbar extension or lack of trunk control during the force production

* Indicates modification of original assessment criteria by McKeown et al. (2014)

Table 7.3 (continued) Modified AAA Scoring Criteria

Original Scoring Criteria (McKeown et al., 2014)				
	Assessment Point	3	2	1
Single Leg Squat off Box (SLS)	Trunk Angle	Maintains perfect trunk posture for all reps	Inconsistent or uncontrolled forward lean and/or movement from lumbopelvic position	Excessive and uncontrolled forward lean and/or movement from neutral lumbopelvic position
	Hip/Knee/Ankle Alignment	Perfect alignment and control of hip/knee/ankle throughout every repetition	Inconsistent form with some perfect repetitions OR minor misalignment on all reps	Poor alignment throughout
	Depth	Hip below knee (below parallel) while maintaining neutral spine for all reps	Depth beyond parallel for some but not all reps	Not able to achieve required depth for any reps
Single Leg Forward Hop (SLFH)	Hip/Knee/Ankle Alignment	Perfect alignment of hip/knee/ankle	Inconsistent form with some perfect OR minor misalignment on all reps	Poor alignment throughout
	Balance/Control	Landing with perfect balance and control	Stick's landing but is unbalanced. Adjustments made via other body movements	No balance/control on landing
	Power Position on landing	Lands in single leg power position/quarter squat after every rep	Inability to land in power position on some but not all reps OR adjusts post landing to attain power position	Excessive hip/knee/ankle flexion. Poor positioning to reproduce force.
Lateral Bound (LB)	Hip/Knee/Ankle Alignment	Perfect alignment of hip/knee/ankle	Slight deviation from ideal landing alignment	Poor alignment throughout
	Balance/Control	Sticks the landing with perfect balance and control	Stick's landing but is unbalanced. Adjustments made via other body movement	No balance/control on landing
	Power Position on landing	Lands in single leg power position/quarter squat after every rep	Inability to land in power position on some but not all reps OR adjusts post landing to attain power position	Excessive hip/knee/ankle flexion. Poor positioning to reproduce force.

* Indicates modification of original assessment criteria by McKeown et al. (2014)

Table 7.3 (continued) Modified AAA Scoring Criteria

Original Scoring Criteria (McKeown et al., 2014)				
	Assessment Point	3	2	1
Push ups (PU)	Scapulohumeral Rhythm	Scapula depression and retraction constant throughout movement. No protraction or elevation of scapular or flaring of elbows	Inconsistent form. Some perfect reps.	Poor scapula positioning and control for all reps
	Body Control	Perfect body control and alignment for every repetition	Perfect body control and alignment on some but not all reps	Poor body control and/or alignment for all reps
	*Complete repetitions	*>10	*4-6	*<4
Prone Hold on Hands (PH)	Upper back/ shoulder position	Scapula depression and retraction constant for 2min No protraction or elevation of scapular	Inconsistent positioning (repositioning throughout the 2min)	Unable to attain correct position
	Hip position	Neutral hip positioning with no anterior/posterior tilt or rotation	Inconsistent positioning (repositioning throughout 2 min)	Unable to attain correct position
	Time	>2min	1-2min	<1min
Lateral Hold on Hands (LH)	Upper/back position	Scapula depression and retraction constant for 2min. No protraction or elevation of scapula	Inconsistent positioning (repositioning) throughout the 2min	Unable to attain correct position
	Mid-Line Alignment	Able to maintain full mid-line alignment with no rotation or side flexion through trunk or hips	Inconsistent positioning (repositioning) throughout the 2 min	Unable to attain correct position
	Time	>2min	1-2min	<1min

* Indicates modification of original assessment criteria by McKeown et al. (2014)

7.4 Statistics

Inter-rater agreement was quantified using Cohen's Kappa statistic. Agreement coefficients were interpreted as <0.0 – poor agreement, 0.01-0.20 –slight agreement, 0.21-0.40 –fair agreement, 0.41-0.60 moderate agreement, 0.61-0.80 –substantial agreement and 0.81-1.00 almost perfect agreement (JR Landis, 1977). The average score of both testers was used to calculate correlations between screening scores and measures of physical performance Analysis of how these relationships were influenced by maturity and playing level was ascertained by dividing players into groups and repeating the calculations.

Shapiro-Wilk test was used to assess normality of data distribution, which then dictated selection of Spearman's or Pearson's correlations coefficients for the assessment of relationships between measures. Correlation strength was described as per (Cohen, 1988), threshold values were 0.1-0.3 (small), 0.3-0.5 (moderate) and <0.5 (large).

An independent sample t-test was used to compare mean screening scores between players of different playing level. Playing level was determined in this case by only classifying players invited national training camps within that year (n=21) (inclusive of top 10 age-group ranked players) as elite, with the remaining 19 players classed as "sub-elite". Effect size was calculated to describe the difference between groups using Hedges' g and the size of this difference was defined as in line with previous definitions (Fritz et al., 2012). The strength of the relationship was considered as ≥ 0.2 small, ≥0.5 medium and ≥0.8 large (Fritz et al., 2012)

7.5 Results

7.5.1 Inter-Rater Agreement

Cohen's Kappa coefficients for inter-rater agreement ranged from moderate to substantial for each screening component (mean = 0.577), with one test (single leg squat left leg) just below the moderate threshold. Due to the large number of points available for each screening (maximum of 117), inter-rater agreement on total score (all components combined) was poor (0.052), with an average difference of 3 points (2.5% ± 1.95%). However, breaking this down further, percentage agreement across 1870 rating points was 75%.

7.5.2 Tennis Performance

National Ranking

Analysis of how physical competency level correlates with overall tennis performance as reflected by National ranking is shown in Table 7.4. Overall competency showed a large negative relationship to ranking (-0.63), which did not differ significantly with maturity. Indicating the higher the total score the lower (better) the ranking of the player within their age group.

Significant correlations of varying strengths from moderate to large were found between national ranking and all individual components apart from the push up (See Table 7.4). The strongest correlations were evident between the higher speed dynamic single leg exercises lateral bound (-0.60 - -0.61) (left and right) and single leg forward hop (-0.50 - -0.51) as well as lateral trunk endurance strength (lateral hold -0.59 - -0.72). Regarding the latter, the relationship was consistently higher on the right side, with this being the dominant side for 80% of players. When left-handers were removed from the analysis the correlation strength increased slightly (-0.76). When separated into maturity groups significant correlations to ranking were stronger within pre-PHV players on all measured parameters apart from single leg squat, this component was only significant post-PHV (See Table 7.4).

Table 7.4 Correlation coefficients between AAA Total Score and individual components with National Ranking

	All (n=40)	Pre-PHV (n=17)	Post-PHV (n=22)
Total % Score	**-0.64**	**-0.66**	**-0.69**
Grand Total	**-0.61**	**-0.69**	**-0.62**
OH Squat	**-0.4**	-0.39	-0.34
SL Squat Left	**-0.41**	-0.30	**-0.46**
SL Squat Right	**-0.34**	-0.14	**-0.46**
Lunge Left	-0.28	**-0.59**	-0.07
Lunge Right	**-0.35**	**-0.58**	-0.26
Lateral Bound Left	**-0.61**	**-0.74**	**-0.50**
Lateral Bound Right	**-0.61**	**-0.63**	**-0.57**
Forward Hop Left	**-0.50**	**-0.58**	**-0.50**
Forward Hop Right	**-0.51**	**-0.62**	**-0.46**
Push Up	**-0.26**	-0.087	-0.35
Front Plank	**-0.39**	-0.34	-0.38
Lateral Hold Left	**-0.59**	**-0.71**	-0.49
Lateral Hold Right	**-0.72**	**-0.93**	-0.60

*__Bold__ font denotes significant correlation.

Playing Level

T-test comparison between playing level groups showed elite players consistently scored higher than sub-elite in overall score and all individual components as reported in Table 5.5. This difference was significant (p < 0.05) in overhead Squat (ES=0.66), walking lunge (right side)

(ES=0.9), lateral bound (ES=0.8-1.2), single leg forward hops (ES= 0.68 – 0.76), prone hold (ES=1.1), lateral hold (ES=1.1- 1.3) components and total screening scores (ES=1.2 total, 1.1 percentage total) (Figure 7.1 and Figure 7.2).

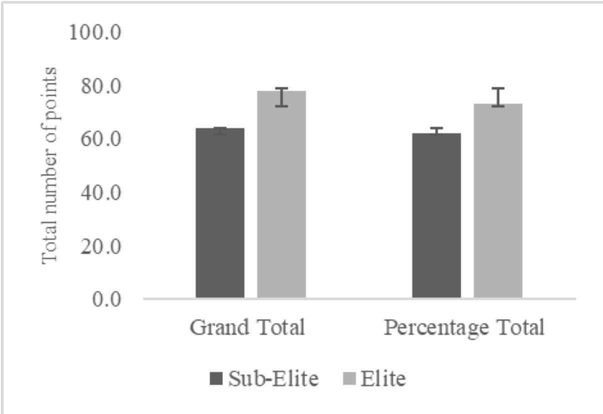


Figure 7.1 Overall AAA screening scores with standard deviations for all participants

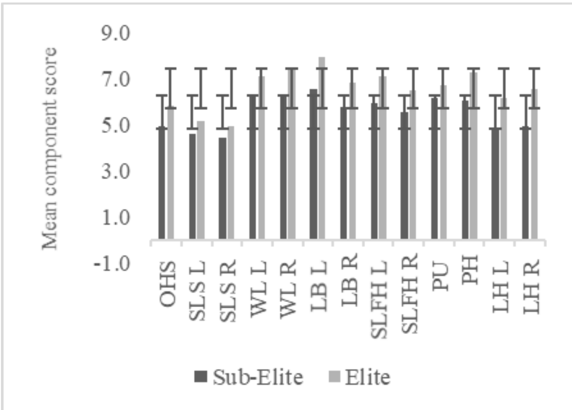


Figure 7.2 Individual component scores with standard deviations for all participants

Serve Velocity and Accuracy

Pre-PHV no significant correlations were found between peak serve velocity (PSV) and any component of the AAA (See Table 7.5). Post PHV large significant correlations were found between walking lunge (bilaterally), left lateral bound, prone hold, right lateral hold and percentage total. The difference between maturity levels meant that significant correlations across all participants were only shown between prone holds and right lateral hold with PSV. The same components showed a significant relationship with MSV in post-PHV participants, but similarly none were present with pre-PHV participants. Again, this equated to significant large correlations with prone hold and right lateral hold across all participants, but additionally with right walking lunge, left lateral bound and percentage total also showed correlations of similar strength.

Table 7.5 Comparison of Elite vs Sub-elite screening scores

	Ranking	N	Mean ± SD	P value	Hedges' g
Overhead Squat	> 10.00	17	4.9 ± 1.2	**0.05**	0.66
	< 10.00	23	5.8 ± 1.5		
Single Leg Squat L	> 10.00	16	4.6 ± 0.9	0.07	0.66
	< 10.00	22	5.2 ± 0.9		
Single Leg Squat R	> 10.00	16	4.4 ± 1.0	0.13	0.6
	< 10.00	22	5.0 ± 1.0		
Walking Lunge L	> 10.00	16	6.3 ± 1.7	0.10	0.48
	< 10.00	23	7.1 ± 1.3		
Walking Lunge R	> 10.00	16	6.2 ± 1.6	**0.01**	0.90
	< 10.00	23	7.4 ± 1.1		
Lateral Bound L	> 10.00	17	6.5 ± 1.5	**0.001**	1.2
	< 10.00	23	7.9 ± 0.9		
Lateral Bound R	>10.00	17	5.8 ± 1.0	**0.012**	0.8
	< 10.00	23	6.8 ± 1.4		
Forward Hop L	>10.00	15	5.9 ± 1.5	**0.04**	0.76
	< 10.00	23	7.1 ± 1.6		
Forward Hop R	>10.00	16	5.5 ± 1.4	0.06	0.68
	< 10.00	22	6.5 ± 1.5		
Push Up	> 10.00	15	6.1 ± 1.5	0.25	0.43
	< 10.00	20	6.7 ± 1.4		
Front Plank	>10.00	17	6.1 ± 1.2	**0.002**	1.10
	< 10.00	22	7.3 ± 1.0		
Lateral Hold L	>10.00	7	4.8 ± 1.1	**0.02**	1.19
	< 10.00	13	6.2 ± 1.2		
Lateral Hold R	> 10.00	7	4.9 ± 1.2	**0.01**	1.33
	< 10.00	13	6.5 ± 1.2		
Total	>10.00	17	63.7 ± 11.1	**0.001**	1.19
	< 10.00	23	78.0 ± 12.6		

* Significant differences are noted in **bold** with $p \leq 0.05$

*L= Left R=Right

Table 7.6 Correlation coefficients between AAA scores and Serve Performance

		OHS	SLS L	SLS R	WL L	WL R	LB L	LB R	SLFH L	SLFH R	PU	PH	LH L	LH R	Total	Percentage Total
Peak Serve Velocity	ALL (n=28)	0.12	0.11	0.24	0.24	0.32	0.33	0.04	0.00	0.00	0.35	**0.42**	0.36	**0.66**	0.16	0.28
	POST-PHV (n=14)	0.42	0.10	0.20	**0.70**	**0.80**	**0.57**	-0.04	0.02	-0.01	0.41	**0.73**	0.57	**0.85**	0.40	**0.63**
	PRE-PHV (n-14)	0.17	0.04	0.29	-0.22	-0.15	0.08	-0.07	-0.33	-0.18	0.37	0.22	-0.06	0.41	-0.18	-0.01
Mean Serve Velocity	ALL (n=28)	0.20	0.20	0.24	0.33	**0.38**	**0.45**	0.07	0.06	0.02	0.37	**0.44**	0.43	**0.71**	0.22	**0.37**
	POST-PHV (n=14)	0.51	0.22	0.18	**0.78**	**0.77**	**0.58**	-0.08	-0.04	-0.05	0.41	**0.75**	0.55	**0.85**	**0.36**	**0.65**
	PRE-PHV (n-14)	-0.07	0.08	0.30	-0.07	-0.01	0.28	-0.05	-0.23	-0.14	0.42	0.25	0.12	0.52	-0.04	0.1
Serve Accuracy	ALL (n=28)	0.28	**0.46**	0.33	0.30	0.33	**0.44**	0.16	0.35	0.11	0.12	0.31	032	0.24	0.34	**0.39**
	POST-PHV (n=14)	0.47	**0.63**	0.49	0.15	0.14	0.45	0.17	0.32	0.26	0.00	0.37	-0.05	0.46	0.26	0.49
	PRE-PHV (n-14)	0.07	0.19	0.07	0.21	0.30	0.30	-0.07	0.12	-0.26	0.36	0.25	0.45	-0.161	0.27	0.21

**Bold* font denotes significant correlation

Serve accuracy showed small correlations to all slow speed lower limb exercises, as well as similar strength relationships to more dynamic exercises but on the left leg only. Of significance left single leg squat, left lateral bound and percentage total proved significant across all participants at moderate - large level.

7.5.3 Physical Fitness Performance, Anthropometry and Maturation

Maturity and Growth

Maturity based on biological age showed significant moderate positive correlation to overall physical competency (0.403 – Percentage total) as shown in Figure 7.3. It also had significant moderate correlations with walking lunge (0.414 - 0.44) and lateral hold (0.404 - 0.398) and a large correlation to performance in hopping (0.50-0.54).

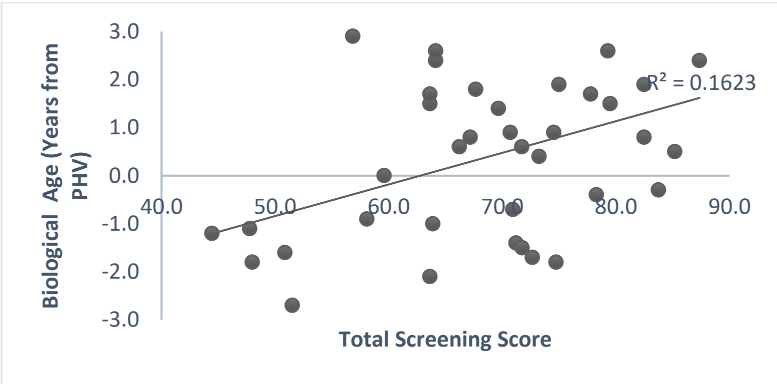


Figure 7.3 Relationship between Maturity and Overall screening score

Height showed a small significant correlation with hop performance (0.34 - 0.35), in addition to a small positive correlation on single leg squat performance on the dominant leg pre-PHV (0.32), but negative post-PHV (-0.31). Height also showed a small negative correlation to OHS ability in post-PHV players (-0.36).

Table 7.7 Correlation coefficients between AAA scores and measures of growth, anthropometry, and fitness

	Height	Weight	Maturity Status	5m Sprint	10m Sprint	20m Sprint	FHAG	BHAG	FHMB	BHMB	OHMB	CMJ	SJ	GSD	GSND	Yoyo	PSV	MSV	Serve Accuracy
OHS	-0.11	0.06	0.14	-0.00	-0.21	-0.26	**-0.32**	**-0.38**	-0.03	-0.01	0.15	0.28	0.29	0.11	0.05	0.25	0.16	0.21	**0.44**
SLS L	0.04	0.17	0.15	**-0.33**	**-0.38**	**-0.36**	**-0.43**	-0.27	0.14	0.12	0.24	0.13	0.15	0.25	0.22	**0.50**	0.29	0.34	**0.54**
SLS R	-0.02	0.13	0.01	-0.19	-0.28	-0.29	**-.38**	-0.31	0.30	0.22	0.31	0.22	0.22	0.30	0.28	**0.50**	0.33	0.30	0.40
WL L	0.12	0.24	**0.41**	-0.26	**-.038**	**-0.39**	**-0.37**	-0.29	0.18	0.22	0.26	0.19	0.22	0.31	0.26	**0.35**	0.28	0.38	0.36
WL R	0.23	**0.34**	**0.44**	-0.27	**-0.37**	**-0.40**	**-0.41**	**-0.34**	**0.39**	**0.41**	**0.32**	0.19	0.19	**0.54**	**0.46**	**0.47**	0.34	0.43	0.41
LB L	0.00	0.05	0.18	-0.11	-0.26	**-0.34**	**-0.53**	**-0.49**	0.09	0.12	0.26	0.24	0.12	0.26	0.31	**0.65**	0.35	**0.44**	**0.62**
LB R	0.13	**0.33**	0.28	-0.23	**-0.39**	**-0.46**	**-0.50**	**-0.55**	**0.37**	**0.39**	**0.57**	**0.38**	0.27	**0.46**	**0.45**	**0.54**	0.04	0.06	0.22
FH L	**0.34**	**0.45**	**0.54**	-0.31	**-0.45**	**-0.50**	**-0.55**	**-0.58**	**0.45**	**0.47**	**0.67**	**0.52**	**0.47**	**0.60**	**0.58**	**0.39**	0.004	0.06	**0.49**
FH R	**0.35**	**0.42**	**0.50**	**-0.47**	**-0.59**	**-0.60**	**-0.50**	**-0.59**	**0.51**	**0.50**	**0.6^2**	**0.51**	**0.42**	**0.62**	**0.61**	**0.42**	0.03	0.03	0.20
PU	0.03	0.11	0.09	-0.22	**-0.34**	**-0.37**	-0.32	-0.28	0.32	**0.36**	0.17	0.22	0.22	0.31	0.28	**0.37**	**0.51**	**0.50**	0.24
PH	-0.08	0.06	0.07	-0.00	0.03	-0.02	-0.05	-0.16	-0.02	-0.01	-0.03	-0.08	-0.03	0.02	0.03	**0.52**	**0.57**	**0.53**	0.29
LH L	0.19	0.23	0.40	-0.22	-0.31	-0.37	**-0.48**	**-0.48**	0.17	0.19	**0.46**	0.23	0.11	**0.45**	**0.45**	**0.53**	0.41	0.44	0.24
LH R	0.23	0.25	0.40	-0.29	-0.34	-0.40	-0.38	-0.36	0.28	0.33	**0.57**	0.24	0.08	**0.47**	**0.52**	**0.48**	**0.75**	**0.75**	0.33
Total	0.01	0.28	0.29	-0.14	-0.23	-0.27	**-0.35**	**-0.35**	0.21	0.23	**0.33**	0.13	0.03	**0.39**	**0.36**	**0.59**	0.27	0.28	0.36
%Total	0.14	0.30	**0.40**	-0.27	**-0.40**	**-0.44**	**-0.53**	**-0.54**	0.30	**0.34**	**0.44**	0.27	0.10	**0.47**	**0.46**	**0.62**	0.39	**0.45**	**0.55**

*Bold font denotes significant correlation.

Abbreviations SCREENING :L=Left, R=Right, OHS=Overhead Squat , SLS =Single Leg Squat, WL=Walking Lunge, LB=Lateral Bound, FH=Forward Hop, PU=Push Up , PH =Prone Hold, LH=Lateral Hold PHYSICAL TESTS: FHAG=Forehand Agility Test, BHAG=Backhand Agility Test, FHMB=Forehand Medicine Ball throw, BHMB=Backhand Medicine Ball throw, OHMB=Overhead Medicine Ball throw, CMJ =Countermovement jump, SJ =Squat Jump, GSD= Grip Strength Dominant, GSND=Grip Strength Non=Dominant , YoYo =YoYo Intermittent Recovery , PSV=Peak serve velocity, MSV=Mean serve velocity

Speed and Change of Direction

A significant negative correlation was found between hop performance bilaterally and all linear sprints, the strength of the relationship increasing with the sprint distance from moderate to large (5m 0.31-0.47,10m 0.45-0.59, 20m 0.50-0.60). Moderate positive correlations were also observed with walking lunge, push up, prone and lateral holds and percentage total score at 10m and 20m.

Single leg squat score on the left leg had a small moderate correlation to speed at all distances (5m; -0.33,10m; –0.38,20m; -0.36), whereas the right leg was insignificant. Pre-PHV-moderate-large correlations were present to bilaterally at nearly all distances (5m; -0.44 - -0.47,10m; -0.54- -0.57, 20m; -0.53- -0.54). Only a moderate correlation (-0.34) with the left leg score and 5m was reported in post-PHV players. In sprints longer than 5m, upper body strength in post-PHV players had moderate correlations to push up performance (10m; 0.45, 20m; 0.48).

Change of direction speed was shown to have a large negative correlation to overall movement competency, as determined by total percentage score (FHAG: -0.53, BHAG: -0.54). The strongest correlations were seen with hopping (FHAG: -0.50 - -0.55, BHAG: -0.58 - -0.59) and bounding (FHAG: -0.49 - -0.52, BHAG: -0.50 - -0.55) on both forehand and backhand sides. Moderate-large correlations with change of direction speed (bilaterally) were also seen with lateral holds (bilaterally) and at a similar level to squatting (OHS and SLS) and walking lunge scores but this was only bilateral on the forehand side. Walking lunge and single leg squat scores on the non-dominant leg for backhand agility were insignificant.

Strength and Power

Upper body power, as determined by medicine ball throwing scores showed moderate correlations to hopping in all throws, the strongest relationship shown in overhead throw (0.62-0.67). Overhead throw also showed a moderate-large correlation to lateral holds (0.46 – 0.57), with moderate correlation to the right side in the backhand throw (0.32). Lateral dynamic stability as represented by the lateral bound exercise, was also only calculated to have a significant correlation on the right leg, again this relationship being strongest in the overhead throw (0.57), and less so in the forehand and backhand throws (0.37 and 0.39 respectively).

Several individual components including single leg squats, walking lunge, lateral bound, forward hopping, push up, prone and lateral holds (Table 7.7) all correlated to upper body strength as represented by grip strength scores at moderate-large level, again most strongly correlated to hopping (Table 7.7).

Squat jump showed moderate correlation to hopping (0.41- 0.46), and lower body power (CMJ) to right lateral bound (0.38) and hopping at a large level (0.51 – 0.52). The pre-PHV group strength scores also showed correlation to single leg squat (0.308 - 0.309) and power to right lateral bound (0.34) and overhead squat (0.32). Post-PHV players had stronger correlations with lateral bound in the CMJ (0.40-0.51) and SJ (0.33-0.48). Additionally, multiple moderate correlations were found between some of the strength focused components such as push up (CMJ; 0.32, SJ; 0.31) and lateral hold (CMJ; 0.34 - 0.46, SJ; 0.34 -0.40).

Endurance

Moderate-large correlations were observed between all components of the screening with the Yo-Yo Intermittent Recovery Endurance test except for overhead squat (See Table 7.7).

7.6 Discussion

This study aimed to ascertain the validity and efficacy of using the AAA movement screen in the assessment of junior tennis players, as a tool to understand an athlete's physical competency and how that might relate to tennis performance. The AAA was found to have good inter-rater reliability and can be carried out in any environment with minimal equipment, supporting use of it as an ecologically valid assessment tool. The results suggested that higher ranked players also had higher screening scores and that this is more evident prior to PHV. Analysis within playing level groups showed elite players scored significantly higher in nearly all tests and total scores.

Previous research has shown better players to have superior fitness qualities when compared to sub elite players (Fett et al., 2017, Ulbricht et al., 2015a) but this is potentially the first to suggest they also have better fundamental movement skills. In terms of the relationship with tennis skill performance, results indicated that physical competency is not an influencing factor on serve velocity pre-PHV, but potentially has some impact in later adolescence. Correlations of individual components also implied that post-PHV, lower limb stability and strength and abdominal strength endurance may explain some of the variance in serve accuracy. Lastly the results suggested that competency in single leg exercises, especially faster ones such as hopping and bounding had the strongest correlations to performance in fitness parameters, particularly to speed and agility measures. Additionally, lateral core strength consistently correlated to measures of upper body power and strength and serve performance. It is acknowledged that these relationships do not equal causation but could be key areas to investigate further in terms of working towards improving overall tennis performance.

7.6.1 The relationship between AAA scores and tennis performance

Ranking and Playing level

National ranking served as the primary measure of tennis performance as this was reflective of a player's performance over time and within their age group, ranking also allowed players to be further sub-categorised as elite (<10) or sub-elite (>10) to observe trends within playing level groups. In alignment with previous research (Kramer et al., 2017a, Kramer et al., 2016a) the results of Chapter 4 reported the presence of superior fitness of elite players, especially as players mature. Likewise, this study showed elite players to have superior FMS when compared to sub-elite players. This aligns with an earlier tennis study which assessed different movement patterns to ascertain differences between elite and club level tennis players aged 11-14 years old. They found a significant difference between playing levels in motor coordination, with elite players having much greater exposure to tennis and S&C training (Söğüt, 2017). Similar results have been found in U18 AFL, the authors also theorised that the noticeable differences in movement competency between players of different developmental ages may be attributed to varying levels of exposure to S&C training (Woods et al., 2015). Both studies and the current results, support the theory forming the basis of many LTAD programmes; that the earlier young athletes acquire a solid athletic movement foundation, the better prepared they are deal with the complexity of sporting movement (Ford et al., 2011, Lloyd and Oliver, 2012, Balyi and Hamilton, 2003). From the data collected on the training habits of NZ players of this age (Chapter 5), elite players in this cohort are statistically more likely to participate in S&C training and have greater S&C training volumes. Given the data above, it would be interesting to use future research to ascertain how introducing S&C players to both younger and sub-elite players would influence their tennis performance and overall physical competency.

Serve Performance

It is believed that this is the first study to use a direct tennis performance measure (serve velocity and accuracy) alongside the AAA screening. Previous studies in other sports have the used the FMS™ protocol with mixed results in terms of finding a clear link between screening scores and sporting performance (Chapman et al., 2014, McGill et al., 2012, Parchmann and McBride, 2011). In this study the moderate correlations between AAA scores and serve velocity (both peak and mean) post-PHV also suggest that movement competency may positively influence serve performance in post pubertal players. The reason why this relationship only becomes significant at a later age is likely to be multifactorial, previous literature has shown serve velocity can be attributed to level of physical conditioning, technique and height (Roetert et al., 2009a, Elliott, 2006). Individual components with the greatest relationship to serve velocity were the walking lunge and abdominal strength endurance. McKeown et al. (2014) described the walking lunge as being able to assess hip and trunk stability, strength and motor control simultaneously and execution is dependent on the multifaceted interaction of these components. The serve requires similar complex coordination of the upper and lower body, demanding sequential activation and coordination of the whole kinetic chain (Abrams et al., 2011, Roetert et al., 2009a, Kovacs and Ellenbecker, 2011b). It is thought that serve performance will not be optimal if any of the links of the chain are not synchronized (Kibler, 2009, Kovacs and Ellenbecker, 2011a). Therefore, it is possible that performance in a fundamental movement involving the whole kinetic chain such as the walking lunge would reflect to some extent the ability to perform a more complex one. This was in fact the case as there was a large correlation (r=0.7-0.8). Pre-PHV players are more likely to be in the earlier stages of skill acquisition, meaning physical ability has less influence on the movement outcome and would be more limited by technique, perhaps explaining the lack of correlation in this age group. This is in agreement with previous research that has shown that accuracy and consistency has greater influence on tennis performance than velocity in this developmental stage (Roetert, 1992). Post-PHV most players are expected to be reasonably technically sound (Balyi and Hamilton, 2003) and therefore are able to add velocity or force afforded by physical development and maturation into the movement (Fett et al., 2018, Hayes et al., 2018, Kovacs and Ellenbecker, 2011a).

The correlations between abdominal strength endurance and serve velocity may allude to the requirement of good trunk strength for effective serve performance. McKeown et al. (2014) used the prone hold on the basis that it reflects the ability to stabilise and control the trunk which creates the foundation of all sporting movements. Whereas the lateral stabilisation assessed in the lateral hold has particular importance within sports where multidirectional control of the body is required (McKeown et al., 2014). It is well-established that the core plays a key role in the kinetic chain in the transfer of force generated by the lower limb to the arm during serving, as well as the attenuation of force to decelerate the racquet on the follow-through (Dobos and NagykÁLdi, 2016, Kovacs and Ellenbecker, 2011a, Roetert et al., 2009a). These results consistently showed the strongest relationship with the right-sided lateral hold, which for 80% of this cohort is their dominant arm. This finding is in contradiction of Sögüt (2016), who found no significant relationship between a modified prone hold (or plank) test with serve velocity. This may be explained in part, by the scoring being purely on time held and not influenced by technique as it is in the AAA, which may allude to other physical qualities influencing serve performance such as kinaesthetic awareness and balance (Sögüt, 2016). Intervention studies aiming to improve serve velocity through increasing trunk strength, have some conflicting results (Smart et al., 2011, Behringer et al., 2013), but variation in methodologies make these difficult to compare. However, it should be noted that most previous studies assessing relationship between strength characteristics and serve velocity, have not included assessment of core strength. Additionally, this study is based on a small sample size (n=14) so will require further investigation to validate these relationships (Fett et al., 2018, Bonato et al., 2015, Pugh et al., 2003, Hayes et al., 2018, Sögüt, 2016).

7.6.2 Relationship between AAA scores and maturity

The link between maturity and total screening score implied that to some small degree, movement competency improves with increasing maturity. This may be expected with the physiological changes afforded by advanced maturity (Lloyd et al., 2014, Valente-dos-Santos et al., 2012a). However, given that this only explained a small amount of variance, it may be fair not to take this as a given and as an element of physical development that needs focused work.

7.6.3 Relationship between physical AAA and physical fitness performance

Many previous studies have attempted to understand the relationship between functional movement scores and performance, via the strength of the relationship with physical tests (Chapman et al., 2014, Lloyd et al., 2015, Lockie et al., 2015a, Parchmann and McBride, 2011, Silva et al., 2017).

Assessment of physical competency of U16 rugby players found the group with lowest screening scores also had the lowest fitness testing scores (Parsonage et al., 2014). Given the prior evidence of superior fitness testing scores of elite tennis players when compared to sub elite it was hypothesized that this would also be the case for young tennis players and the results of this study agree with this theory (Fett et al., 2017)

There are number of correlations within this study which suggest a positive link between competency measures and performance in fitness tests, which agrees some previous research and opposes others (Okada et al., 2011, Parchmann and McBride, 2011). Several of them appear more random in nature or only present unilaterally, which raises questions on the real value of these correlations. For example, the positive correlation between lateral bound and walking lunge on the right side and throwing measures. The implication may be that the better the score in the movement tests the further the throw, which seems illogical that this would not be bilateral as both feet are planted, and the front foot is alternated. Noting that these correlations do not equal causation, trying to make sense of these results on these more random results may be unwise and suggest further research is required.

Therefore, regarding the more compelling correlations in this study, results support previous research denoting the positive relationship between screening measures assessing lower limb strength and stability to speed and agility performance (Lloyd et al., 2013). The significant link between the overall screening scores to change of direction performance (forehand and backhand agility tests), aligns with previous concepts emphasising the importance of development of FMS patterns during the early years to allow these skills to be tested in more open, complex sporting situations. (Oliver et al., 2013, Lloyd et al., 2013) proposed that agility training for youth athletes consists of three components; FMS, change of direction speed (CODS) and reactive agility training. It is hypothesised that having superior FMS skills would contribute to enhanced agility. Out of all individual components assessed in the screening, the most prominent results were that those with better hopping and bounding scores had faster speed and change of direction scores. These correlations may suggest that increased focus on the ability to stabilise and decelerate on one leg may be of upmost importance in the FMS development of young tennis players and is something that needs further investigation. Hopping consistently produced moderate to large correlations to nearly all fitness parameters and is a movement capable of reflecting the ability to stabilise and reduce force efficiently in a unilateral environment (McKeown et al., 2014). Likewise, lateral bound similarly requires ability to stabilise and reaccelerate in a lateral direction and had comparable correlations to change of direction speed measures. Arguably, this may be an area of even greater importance for young tennis players as 70% of tennis movement is in a lateral direction.

In speed measures, exponential growth was seen in correlation strength with hopping and increasing sprint distance, theoretically aligning with the rise in strength demands required to continue increase acceleration towards top speed (McBride et al., 2009). This suggests that players with better single leg strength and stability as reflected in their competency controlling a simple dynamic task such as a forward hop, may enable better sprint performance. Previous studies have established that resistance training is effective method of enhancing speed in children and adolescents (Oliver et al., 2013, Behringer et al., 2011, Rumpf et al., 2012). Assuming deficits in this area would lead to poorer performance, the hop test may provide useful information to guide exercise prescription designed to enhance performance.

It is also important to consider that the current data has also shown elite players to have higher mean tennis training volumes and this has been previously shown to influence physical fitness (Opstoel et al., 2015, Sanchis-Moysi et al., 2011). This is a factor previously shown to produce more pronounced sport-specific characteristics and superior motor coordination and physical fitness in prepubescent athletes (Opstoel et al., 2015). Prepubescent tennis players in comparison to non-active controls have shown better aerobic power, sprint scores, jump performance and lower body fat percentage (Sanchis-Moysi et al., 2011). However increasing training to five days per week from twice a week provided only a small additional increase in these physical measures (Sanchis-Moysi et al., 2011). This creates a lack of clarity on the exact influence of tennis training on youth physical development. Additionally, numerous factors can influence the physiological effect of training on an individual such as environment, court surface, intensity, coaching style, group or individual sessions (Murphy et al., 2014, Murphy et al., 2015b). As discussed earlier in this thesis, studies of other junior tennis populations found elite players to have both higher tennis training and physical training volumes than sub-elite players (Fett et al., 2015, Sánchez-

Muñoz et al., 2007). Thus, reinforcing support for the requirement for high volumes of both types of training to enable elite tennis performance. Based on this information, results of the previous chapter and anecdotal observations of training volumes in NZ tennis players, the key takeaway for tennis coaches is to highlight that high volumes of tennis training alone are unlikely to be sufficient for producing a player capable of competing at elite international level.

7.6.4 Limitations

The main limitations to this study are largely linked to the lack of sensitivity of the scoring criteria of the movement screen. To score maximum points in any area the movement must be close to perfect, therefore providing no differentiation between an athlete performing a movement at an average level (2/3) and another performing it very well, but with a minor compensation.

In hindsight, although the chin-up exercise was removed as it could not be performed on court, it would have been better to replace it with another pulling exercise such as supine row on portable bars. This may have provided valuable information about push-pull ratio in tennis players and information on the relationship of the posterior chain strength to other measures.

Lastly, given the age of the cohort, it is possible some players would have required a longer familiarisation period to perform optimally and therefore may limit reliability of the data.

7.7 Practical Applications

The initial findings of this study suggest fundamental movement skill competency can be linked to an athlete's physical fitness ability, which in turn has been shown to be correlated to tennis performance. Therefore, giving merit to the process of assessing this as part of understanding the exercise prescription requirements for junior tennis players. This data does not tell us whether this correlation has any predictive ability to use this screening as method of talent identification, but potentially reinforces the positive impact having a solid movement foundation can impact sporting performance. As a screening tool, the AAA has similar ecological validity to other screenings in the sense it can be done in a gym or on court with minimal equipment. Although two components (hopping and bounding) showed the strongest correlations to multiple parameters measured, that is not to say the other components lack validity and may provide valuable information to the S&C coach from other perspectives. It would be beneficial to focus future research on how training interventions to improve FMS influence performance in the fitness and tennis skill parameters measured in this study or affect ranking over time. It also opens the conversation around the introduction of S&C pre-PHV to work on the development of FMS earlier than is currently practiced in NZ.

7.8 Conclusion

It appears the assessment of movement competency via the AAA movement screen may be a valuable tool for S&C coaches with junior tennis players. Significant relationships between screening scores and performance provide validity of this assessment. Indicating that data gathered may provide insight into strengths and weaknesses of an individual's movement competency, which in turn can help guide exercise prescription to enhance performance. Lastly, it has good ecological validity as it requires minimal equipment and time to complete, meaning that it can be widely applied by coaches working with junior tennis players in any environment.

Chapter 8 – The impact of a 6-week FMS training intervention on the movement competency, fitness and tennis performance of junior tennis players aged 10-15 years old.

8.1 Preface

It was as discussed in the introduction of this thesis, that evidence supporting the importance and potential rewards of early competitive success can often encourage a quantity over quality approach to competing, leaving limited time for physical development. Therefore, optimising physical training time prior to players starting to compete internationally may be of key part of creating resilience in young players' ability to cope with the demands of heavy U18 tournament schedule. For most, this preparatory period is between the ages of 10-14 years old during the stages of preadolescence and early adolescence. Results of Chapter 5 showed NZ players dedicate significantly less time to S&C than their international peers and are less likely to be in a structured training environment until they reach U14 level. Finding methods of physical training which are manageable for most youth players may be a key contribution to future success of NZ players. Based on the positive relationship found between movement competency and performance in Chapter 7, this study investigated the effects of an ecologically valid FMS training intervention for players of this age group on physical and tennis performance.

8.2 Introduction

The term FMS covers a wide spectrum of motor skills inclusive of both locomotor and object control skills, development of which starts in infancy (Logan et al., 2012). However this does not happen naturally through the process of maturation, but needs to be learned, practiced and reinforced (Logan et al., 2012). The Youth Physical Development model (YPD) described by Lloyd and Oliver (2012) promotes FMS as the main training focus up to the onset of puberty, with the idea being to progress to shift emphasis onto sport specific training when the athlete reaches a satisfactory level of competency. The purpose of FMS training for youth athletes is not only to develop physical competency, but to correct dysfunctional movement patterns, imbalances and asymmetries which are well established to have the potential to impair performance and/or play a part in the aetiology of injury (Ellenbecker et al., 2009, Roetert et al., 2000, Kibler and Chandler, 2003). Previous research has indicated that this is an essential stage for youth athletes to ensure safe and effective performance of more complex sports movements at a later stage (Lloyd and Oliver, 2012).

There is a large body of research that has evaluated the impact of training programmes focused on the development of both general fundamental movements and specific exercises targeting motor control deficits and the underlying components which enable proficiency in these areas (Myer et al., 2013). This research has consistently demonstrated improvements in selected performance measures in youth of all stages of maturation (Song et al., 2014, Wright et al., 2015, Wrotniak et al., 2006). Equally it has also repeatedly shown that poor physical fitness, resulting in decreased strength and poor FMS, is likely to play a primary role in sport related injury and potentially linked to subsequent burnout or dropout from sport (Myer et al., 2013, Faigenbaum et al., 2009, Faigenbaum and Myer, 2010, Lloyd et al., 2012a). A recent study in young tennis players was able to highlight this relationship between poor FMS and risk of injury (Filipcic and Filipcic, 2019). They used the FMS™ to screen 181 young tennis players (age 11-16) and followed their injuries for the following 6-months categorising them in 4 groups (no injury, light injury, moderate injury) (Filipcic and Filipcic, 2019). Uninjured players had the highest FMS score and those who acquired serious injury to have the lowest scores. Data showed the players in the serious-injury group, to have greater weekly tennis training volumes and to have played tennis longer than those in the other 3 groups. Lastly and key to the objective of this study, their results showed those with a larger number of S&C training hours in the following 6-month period had a statistically significant decreased risk of serious injury (Filipcic and Filipcic, 2019). This suggests that the greater volume of S&C training may have significant positive impact on reducing injury, therefore enabling players to continue training and competing.

For the recreational youth athlete it would generally be recommended that FMS competency is achieved through participation in both structured physical training and playing multiple sports without specialising early (Baker et al., 2017). For elite players who may have specialised early and have high competition demands this process may need to be streamlined to be more efficient and effective. Using movement screening results, permits corrective exercises to be prescribed in an informed manner specifically aimed at the athletes own individual deficits (Bodden et al., 2015). It also avoids attempting to build sport-specific fitness onto an insufficient athletic foundation which is theorised to make the athlete more susceptible to injury (Cook, 2010, Bodden et al., 2015). Tennis literature has also historically in theory aligned with current opinion, recommending that tennis players must first develop a sound base of physical fitness, after this competitive players can progress to conditioning for sport specific movement and injury prevention (Chandler, 1995). Yet recent research has highlighted the distinct lack of time available for elite players to dedicate to becoming a well-rounded athlete and players seldom reach optimum athletic development (Ulbricht et al., 2013, Kovacs, 2016).

There is limited research analysing the effects of an FMS training block designed to enhance all around competency on the physical and tennis performance of young tennis players. To the authors knowledge just one study of a similar nature has been implemented on very young tennis players (8-10 years old) (Yildiz et al., 2019). Yildiz et al. (2019) used a "functional training" (FT) programme intervention with the focus on the development of the target movement quality with the goal of improving fundamental movements. The authors compared this to a "traditional training" (TT) programme focused on unidirectional movements and strength development in specific muscle. Across 8 weeks, the FT group made significant improvements ($p<0.01$) in all measured parameters of athletic performance, whilst the TT group saw an increase in dynamic balance only but saw a decrease in FMS score. They concluded that in alignment with LTAD literature (Besier et al., 2001, Lloyd and Oliver, 2012) training focused on enhancing the overall movement competency of players of this age was more effective than training specific muscle groups (Yildiz et al., 2019)

Subsequently, there is a dearth of information on how this type of training may impact players aged 10-14 years, who may not have developed satisfactory FMS in their previous training or experiences. This information would be useful for S&C coaches who are having players enter a more structured training environment at this time. Therefore, the purpose of this study was to investigate the use of a FMS based programme as a method of enhancing physical competency, athletic ability and tennis performance within young tennis players.

8.3 Methods

8.3.1 Subjects

20 players (8 males and 12 females) aged 10-15 years participated in the study. Participant age and physical characteristics are presented in Table 8.1. Players volunteered to participate and were included if they described tennis as their main sport, played at least three times per week, were free from injury and did not participate in any form of structured S&C. Participant playing level varied significantly with respective age-group national rankings ranging from 1-500. Biological maturity was determined using the Mirwald equation (Mirwald et al., 2002). For those who fell within the margin for possible error (± 0.6yrs from PHV), a secondary subjective assessment of physical appearance (non-invasive only) was made by the primary researcher to help minimise error in categorisation.

Table 8.1 Descriptive statistics of all subjects

	ALL	PRE-PHV	POST-PHV
n	20	9	11
Age (years)	13 ± 1.8	11.5 ± 1.3	14.2 ± 1
Height (cm)	157.8 ± 10.7	149.1 ± 7.5	164.9 ± 7
Weight (kg)	47.8 ± 11	39.2 ± 5.7	54.9 ± 9

8.3.2 Procedures

Testing

Pre and post-test testing sessions took place on the weekends directly before and after the 6-week intervention programme. Both testing and training sessions took place at the same indoor tennis facility on an indoor hard court. All participants completed the same physical testing battery and tennis skill tests as described in Chapter 4, in addition to the Yo-yo Intermittent Recovery test described in Chapter 6. The tests were completed in the following order: the modified AAA screening, physical testing battery and serve velocity and accuracy test. For all tests, participants were permitted practice attempts and to ask questions to help with familiarisation and limit the potential for learning effect to influence the post-test results. Chapter 7 highlighted limited correlations between single leg squat test in the AAA and testing measures, it was therefore deemed appropriate to remove from the screening battery in the interest of time efficiency. Likewise, participants in chapter 7 showed little to no difference in prone hold and lateral hold tests, therefore only the prone hold was used to assess trunk strength endurance in this study. Three assessors scored the screenings with aim of reducing bias created from expectation of improvement, Assessor 1 scored both pre and post-test screenings, Assessor 2 pre-test only and Assessor 3 post-test only. The test-retest reliability of the fitness measures reported below reflect intra-session reliability, with each test being repeated multiple times as there was no scope to repeat the tests in the following few days with this cohort.

Table 8.2 ICC values and CVs of Interrater agreement

PRE-TEST TESTER 1 VS TESTER 2	CV	Intraclass Correlation	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound	P
Overhead Squat	5.7	.956	0.88	0.98	<0.001
Walking Lunge Left	4.9	.947	0.86	0.98	<0.001
Walking Lunge Right	5.4	.938	0.84	0.98	<0.001
Lateral Bound Left	4.5	.930	0.82	0.97	<0.001
Lateral Bound Right	6.9	.789	0.51	0.92	<0.001
Forward Hop Left	5.8	.952	0.87	0.98	<0.001
Forward Hop Right	7.7	.885	0.70	0.96	<0.001
Push Up	5.0	.888	0.70	0.96	<0.001
Prone Hold	6.40	.887	0.72	0.96	<0.001
Lateral Hold Left	3.5	.886	0.48	0.98	<0.001
Lateral Hold Right	3.6	.896	0.52	0.98	<0.001

POST TEST TESTER 1 VS TESTER 3	CV	Intraclass Correlation	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound	P
Overhead Squat	5.9	.967	0.91	0.99	<0.001
Walking Lunge Left	6.4	.838	0.62	0.94	<0.001
Walking Lunge Right	10.4	.769	0.48	0.91	<0.001
Lateral Bound Left	11.0	.900	0.75	0.96	<0.001
Lateral Bound Right	16.8	.770	0.49	0.91	<0.001
Forward Hop Left	12.1	.891	0.73	0.96	<0.001
Forward Hop Right	8.1	.836	0.61	0.94	<0.001
Push Up	7.7	.957	0.89	0.98	<0.001
Prone Hold	7.6	.945	0.86	0.98	<0.001
Lateral Hold Left	6.2	.981	0.95	0.99	<0.001
Lateral Hold Right	8.3	.964	0.91	0.99	<0.001

Table 8.3 Reliability CV's and ICCs for all fitness and tennis testing measures

TEST	CV	Intraclass Coefficient	95% Confidence Interval Lower Bound	Upper Bound	P
CMJ	7.1	0.87	0.70	0.94	<0.01
SJ	5.6	0.90	0.76	0.96	<0.01
5m Sprint	2.7	0.70	0.40	0.87	<0.01
10m Sprint	2.5	0.77	0.52	0.90	<0.01
20m Sprint	1.6	1.00	1.00	1.00	<0.01
FHAG	3.0	0.75	0.47	0.89	<0.01
BHAG	2.0	0.90	0.77	0.96	<0.01
FHMB	4.2	0.94	0.86	0.98	<0.01
BHMB	4.8	0.93	0.83	0.97	<0.01
OHMB	4.5	0.96	0.91	.98	<0.01
GSD	10.6	0.82	0.60	0.92	<0.01
GSND	8.5	0.95	0.87	.98	<0.01
PSV	12.2	0.52	0.12	0.77	0.01

Training

All participants completed the six-week intervention programme which consisted of two sixty-minute training sessions on court per week. The programme for both sessions comprised of exercises focused on six key areas of fundamental movement: squat, lunge, hinge, single leg stability, landing mechanics and trunk strength (Table 8.4). Due to the substantial demands for lateral movements in tennis, each session was further broken down to specifically focus on two different planes of movement: lateral and linear. Six levels of difficulty were devised to allow for the varying abilities within the training group, participants starting level for each movement component was allocated based on individual scores in the respective screening movement. Each movement in the AAA was scored out of 9 points, therefore participants scoring 0-3 were assigned to level 1, 4-6 to level 3 and 7-9 to level 5. Progression was permitted when the individual had completed a minimum of two sessions and an assessment of competency at the current level by one of the S&C coaches leading the session. Each key movement pattern had a superset of other essential components of FMS including static and dynamic balance, coordination and flexibility. The session started with a standardised 10-minute warm up comprising of a cardiovascular component, dynamic stretches, basic locomotor skills such as hopping, jumping and change of direction and activation exercises. Participants then completed the 40-minute intervention programme in a circuit of 12 stations allowing for the 6 key movement patterns and their relevant superset to be repeated three times. The session concluded with a game-based activity focused on challenging object control skills such as throwing, catching and more dynamic locomotor skills such running and change of direction.

Table 8.4 Multilevel FMS Training Programme

EXERCISE	SQUAT	LUNGE		LANDING MECHANICS		SINGLE LEG STABILITY	PUSH UP	SHOULDER STABILITY	CORE	
		LINEAR	LATERAL	LINEAR	LATERAL				LINEAR	LATERAL
LEVEL 1	Box Squat	Static Lunge (Split Squat)	Static Lateral Lunge	Counter movement jump and stick landing	Lateral bound and stick – slow and controlled	Single leg Squat to box (1 foot down 2 feet up)	Wall Push up	4-Point kneeling shoulder touches	Front plank 30s	Kneeling side plank 30s
LEVEL 2	Body Weight squat to <90 degrees	Walking Lunge	Dynamic Lateral Lunge	Broad jump	Lateral bound and stick - fast	Single leg squat to box (1 foot down 1 foot up)	Kneeling push ups	4-point kneeling superman raises	Front plank 1min+	Kneeling side plank 1min
LEVEL 3	Overhead Box Squat with Dowel	Walking Lunge with Rotation with med ball	Lateral lunge with Rotation with resistance band	Single leg hops to two foot landing	Lateral Hop and Stop	Single squat on box	Incline push ups	Shoulder touches kneeling push up position	Press up plank 30s	Kneeling side plank with leg raise 30s
LEVEL 4	Overhead Body Weight Squat to <90 degrees	Backwards Lunges	Lateral lunge with rotation using med ball	Single leg hop forward to single leg landing	Lateral rebound hop and stop	Overhead Single leg squat on box with dowel	Push Ups	Shoulder touches push up position	Press up plank 1min+	Kneeling side plank with leg raise 1min
LEVEL 5	Overhead Squat to box with training bar	Loaded walking lunges	Lean and fall into lateral lunge with rotation using resistance band	Hurdle CMJ	Lateral hurdle hop and hold landing	Single leg squat standing (minimum depth 90 degrees flexion)	Rotational Push Up	Frontal raises in push up position	Front plank with alternating leg raises 30s	Side plank 30s
LEVEL 6	Overhead Squat to <90 degrees with training bar	Loaded walking rotational lunges	Lean and fall into lateral lunge using med ball	Continuous Broad Jump	Lateral hurdle rebound hop and stop	Overhead Single leg squat standing (minimum 90 degrees depth)	Single leg push up (one leg raised)	Superman on toes	Front plank with alternating leg raises 1min+	Side plank 1min+

8.4 Statistics

The movement screening was scored by two independent raters who marked movements against the previously described template in Table 7.2 (Chapter 7) and were blinded to the scores of the other. Both raters had 5+ years' experience as qualified S&C coaches, with the second rater also a qualified physiotherapist. Inter-rater agreement was quantified using intraclass correlation coefficient (ICC) and coefficient of variation (CV). ICC estimates and their 95% confidence intervals were calculated using SPSS (Version 25) using two-way random, single measures and consistency model. ICC were interpreted based on the scale indicating values <0.5 having poor reliability, 0.5-0.75 moderate reliability, 0.75-0.9 good reliability and values >0.90 indicate excellent reliability (Koo and Li, 2016). CV was calculated using an Excel CV calculator (Kwon 1996). It has been reported in tests with a CV of <10% the variation can be considered low, although there is some suggestion a score of <5% may be more appropriate for fitness tests (Turner et al., 2015). Combining these two measures (ICC and CV) (Bradshaw et al., 2010) suggests variability as small with an ICC > 0.67 and CV < 10%, moderate when ICC < 0.67 or CV > 10% and large when ICC < 0.67 and CV > 10.

Shapiro-Wilk was used to assess normality of data distribution. Once normality was established a paired samples t-test was used to compare pre-test and post-test means of two groups based on biological maturity. Significant changes in means were identified when p≤ 0.05. Effect size was calculated to describe the magnitude of the change using Hedges' g and this size was defined as in line with definitions of size of change (Fritz et al., 2012). The strength of the relationship was considered as ≥ 0.2 small, ≥0.5 medium and ≥0.8 large (Fritz et al., 2012)

8.5 Results

8.5.1 Reliability

The reliability of the fitness test measures was assessed using CV and ICC from the same group of athletes most recent testing scores and are reported in Table 8.3. ICC and CV values showed generally good to excellent scores of reliabilities between the three different individuals scoring the movement screening (1 rater scoring only pre, 1 only post and 1 both), reflecting a good level of interrater agreement. Greater variation was seen between the two testers assessing the post-test scores, meaning the CV scores for lateral bound on both sides and forward hop on the left were <10%. However, their respective ICC scores still fell within the >0.75-0.90 category indicating "good" reliability or "moderate" when combing the two measures.

8.5.2 Compliance

21 players initially signed up to participate in the study, with two players failing to make the 85% compliance threshold due to illness, meaning a total of 19 completed the whole intervention. Additionally of the 19, 3 players missed their post intervention screening due to school commitments meaning only 16 players were included in the analysis.

8.5.3 Training Intervention Effects

Fitness and Tennis Testing

There were notable differences of the impact of the intervention between the two maturity groups on the measures of fitness and tennis skill. Both groups saw significant changes in age, height and weight.

Pre-PHV players saw improvement in all measures, with the only exception being linear speed. These improvements were significant ($p<0.05$) in countermovement jump, backhand medicine ball throw, overhead medicine ball throw and Yo-yo distance, effect size was medium-large in all parameters (0.41,0.45,0.56, 0.39 respectively) (see Table 8.5).

Post-PHV players showed improvement in countermovement jump, forehand agility, forehand medicine ball throw, backhand and overhead medicine ball throws, Yo-Yo Distance, grips strength (dominant and non-dominant) and sit and reach. However only the improvement in hamstring flexibility (Sit and Reach test) was statistically significant ($p=\leq0.05$) but was small in magnitude (effect size=0.18).

Both groups showed improvement in peak and mean serve velocity and serve accuracy (see Table 8.6), but this was not found to be statistically significant.

Table 8.5 Fitness testing: Pre and Post-test group means and effect sizes; Pre-PHV and Post-PHV

	PRE-PEAK HEIGHT VELOCITY				POST PEAK HEIGHT VELOCITY			
	Pre-test	Post-test			Pre-test	Post-test		
Test	Mean ± SD	Mean ± SD	p	Hedges' g	Mean ± SD	Mean ±SD	p	Hedges' g
CMJ (cm)	26.2 ± 4.3	**28.1 ± 4.30**	**0.04**	**0.41**	29.0 ± 5.90	29.50 ±5.30	0.52	0.08
SJ (cm)	24.7 ± 3.4	25.8± 4.00	0.26	0.26	27.7 ± 5.0	26.90 ± 5.00	0.45	-0.14
5m Sprint (s)	1.22 ± 0.04	1.23 ± 0.06	0.06	0.25	1.13 ± 0.07	1.16 ±0.04	0.13	0.36
10m Sprint (s)	2.11 ± 0.06	2.14 ± 0.08	0.3	0.14	1.97 ± 0.09	2.01 ± 0.06	0.08	0.34
20m Sprint (s)	3.83 ± 0.16	3.84 ± 0.20	0.62	0.1	3.40 ± 0.15	3.50 ± 0.10	0.16	0.12
FHAG (s)	2.57 ± 0.14	2.57 ± 0.14	0.94	0.13	2.45 ± 0.09	2.44 ± 0.11	0.76	-0.35
BHAG (s)	2.64 ± 0.12	2.63 ± 0.13	0.85	0.12	2.51 ± 0.11	2.52 ±0.09	0.79	-0.23
FHMB (m)	8.8 ± 1.30	9.10 ±1.40	0.12	0.2	10.30 ± 1.30	10.80 ± 1.20	0.16	0.36
BHMB (m)	7.9 ±1.30	**8.6 ± 1.50**	**<0.01**	**0.45**	9.90 ± 1.10	10.04 ± 1.20	0.55	0.1
OHMB (m)	6.7 ± 0.70	**7.30 ± 1.00**	**0.05**	**0.56**	8.60 ± 0.96	8.80 ± 1.30	0.3	0.13
Yo-yo Distance (m)	693 ± 255	**804 ± 291**	**0.02**	**0.39**	880 ± 305	888 ±352	0.83	0.02
GSD (kg)	21.9 ±3.80	23.30 ± 4.00	0.2	0.32	32.90 ± 4.30	33.50 ± 4.20	0.46	0.13
GSND (kg)	18.2 ± 3.60	18.80 ± 3.31	0.61	0.13	28.40 ±4.20	28.80 ± 4.10	0.66	0.07
Sit and Reach Test (cm)	22.4 ± 6.40	23.4 ±8.30	0.28	0.13	31.00 ± 11.40	**33.00 ± 12.10**	**0.05**	**0.18**

*__Bold__ font indicates significant change in mean.

Table 8.6 Tennis Skill testing: Pre and Post-test group means and effect sizes; Pre-PHV and Post-PHV

	PRE-PEAK HEIGHT VELOCITY				POST PEAK HEIGHT VELOCITY			
	Pre-test	Post-test			Pre-test	Post-test		
Test	Mean ± SD	Mean ± SD	p	Hedges' g	Mean ± SD	Mean ± SD	p	Hedges' g
PSV (kmph)	112.7 ± 17.6	113.1 ± 25.3	0.91	0.10	120.7 ± 17.7	122.3 ± 14.5	0.53	0.03
MSV (kmph)	103.5 ± 18.6	104.1 ± 22.3	0.82	0.03	114.8 ± 17.0	115.8 ± 15.1	0.70	0.06
Serve Accuracy (Score out of 24)	6.20 ± 2.60	7.10 ± 2.80	0.30	0.30	6.80 ± 2.60	6.90 ± 2.70	0.86	0.04

*****Bold** font denotes significant change in mean

8.5.4 Movement Screening

The results of the pre-test and post-test screening are reported in Table 8.8. Pre-PHV players improved 6/9 measured parameters, as well as total score. This was only statistically significant in the overhead squat (p=0.007), with a medium effect size (0.34).

When analysed on an individual basis, percentage change in total score varied greatly between players, with 7/8 showing improvement between 0-16.7% and 1 player showing a decrement of -6.5% (See Fig 8.1).

Post-PHV players showed improvement in 7/9 components, in addition to total score. These improvements were statistically significant in overhead squat, lateral bound (right only), push up and total. The magnitude of these changes varied from medium in overhead squat (0.48), push up (0.35) and total (0.34) to a large effect size seen in lateral bound right (0.88).

Similarly, to pre-PHV there was notable variation in percentage change in total score, with 7/8 players showed improvement between 1.5-21.4% and 1 player saw a negligible decrement of -0.9%.

Table 8.7 Modified AAA screening: Pre and Post-test group means and effect sizes; Pre-PHV and Post-PHV

	PRE-PEAK HEIGHT VELOCITY				POST PEAK HEIGHT VELOCITY			
	Pre-test	Post-test			Pre-test	Post-test		
Test	Mean ± SD	Mean ± SD	p	Hedges' g	Mean ± SD	Mean ± SD	p	Hedges' g
Overhead Squat	5.4 ± 1.8	**6.0 ± 1.7**	**0.01**	**0.34**	5.7 ± 1.6	**6.6 ± 2.1**	**0.04**	**0.48**
Walking Lunge Left	5.8 ± 1.6	6.0 ± 0.9	0.6	0.15	6.4 ±1.3	6.8 ± 1.2	0.08	0.32
Walking Lunge Right	5.6 ± 1.5	6.5 ± 1.2	0.10	0.64	6.8 ± 0.9	6.6 ± 0.9	0.48	0.22
Lateral Bound Left	6.3 ± 1.1	6.0 ± 1.0	0.32	0.28	7.3 ± 1.3	7.3 ± 1.1	1	0
Lateral Bound Right	5.9 ± 1.3	5.8 ±1.2	0.89	0.07	6.1 ± 0.9	**6.9 ± 0.9**	**0.03**	**0.88**
Forward Hop Left	5.5 ±1.6	5.9 ±1.3	0.18	0.28	6.7 ± 1.1	7.3 ± 1.1	0.1	0.54
Forward Hop Right	5.4 ± 1.6	5.7 ± 1.3	0.69	0.2	6.2 ± 0.8	6.4 ± 1.3	0.68	0.18
Push Up	6.0 ± 1.5	6.0 ± 0.9	0.89	0.32	6.0 ± 1.6	**6.5 ± 1.6**	**0.02**	**0.35**
Front Plank	6.5 ± 0.7	6.3 ±1.1	0.59	0.21	6.3 ± 1.5	6.5 ± 1.1	0.57	0.15
Total	50.1 ± 8.4	52.6 ±7.6	0.11	0.31	53.6 ± 11.4	57.3 ± 10.1	0.05	0.34

***Bold** font denotes significant change in mean

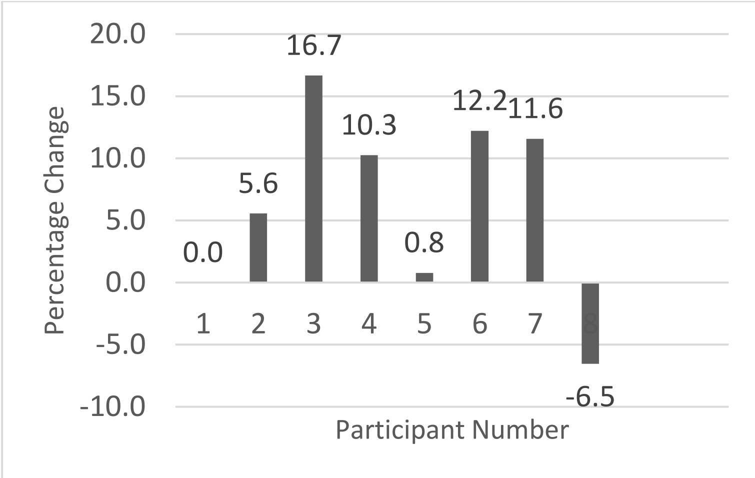


Figure 8.1 Individual Percentage Change in Screening Scoring in Pre-PHV Players

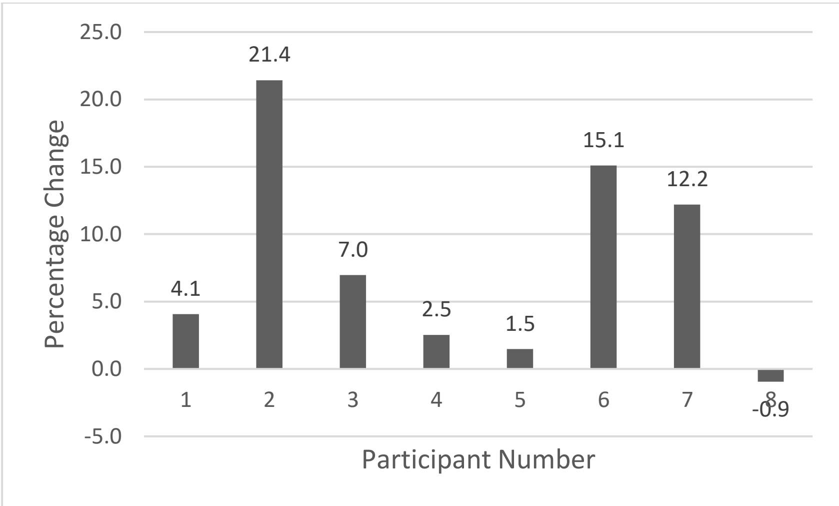


Figure 8.2 Individual Percentage Change in Screening Scoring in Post-PHV Players

Table 8.8 Pearson's Correlations between significant changes in performance with movement competency

	Pre-Peak Height Velocity				Post Peak Height Velocity
TEST	Countermovement jump	Backhand Medicine Ball Throw	Overhead Medicine Ball Throw	Yo-yo Intermittent Endurance	Sit and Reach test
Overhead squat	-0.20	-0.48	-0.15	-0.24	-0.57
Walking Lunge Left	0.62	-0.02	0.33	0.00	0.70
Walking Lunge Right	0.16	0.02	0.04	-0.16	-0.29
Lateral bound left	-0.51	-0.53	-0.45	0.00	0.65
Lateral bound right	-0.66	-0.65	0.10	0.27	0.02
Forward hop left	-0.19	-0.53	-0.01	-0.35	-0.05
Forward hop right	0.42	-0.69	0.41	0.67	0.20
Push up	**-0.76**	0.21	0.27	-0.09	-0.56
Front plank	-0.20	0.61	0.64	-0.23	0.03
Total	-0.47	-0.48	0.56	0.16	0.16

*Bold font denotes significant correlation.

8.6 Discussion

The main objective of this study was to ascertain the effects of an FMS training intervention on players aged 10-15 years with a low S&C training age. It was proposed that introducing this type of training would enhance overall physical competency and subsequently enable improved performance of fitness and tennis specific tests. Due to the physical differences in maturation within this age group, results were analysed within two separate maturity groups (Pre-PHV and Post-PHV).

In terms of the reliability of the measures used to assess both fitness and tennis skill, except for the serve test, produced CV values of <10% (see Table 8.3) meeting the generally accepted level of reliability (Turner et al., 2015). The serve velocity test fell above this benchmark at 12.2%, however this may be due to the fact players of this age may choose to vary velocity of the serve to achieve greater accuracy. Additionally, most of the CV's were <5% which has been suggested may be more suitable for interpreting fitness tests data (Turner et al., 2015).

Participants in the pre-PHV group responded positively to the intervention, with overall improvements in most parameters of physical fitness and tennis skill, with four statistically significant changes. Large variation in individual improvement in the movement screening (5-16%) amongst this group may have contributed a lack of meaningful change in competency scores, with significant change observed in overhead squat only.

Likewise post-PHV players also responded positively overall to the intervention, however more significant improvement was noted in movement competency (total score, overhead squat, lateral bound (right) and push up). But as may be expected given their advanced maturation, the FMS intervention had less impact on physical fitness and tennis testing scores. Although the biggest improvements were seen in similar components as pre-PHV, significant change was only noted in flexibility. Again, a large variation in individual response to the intervention on screening scores was observed, which was perhaps reflective of the differences in baseline levels at the beginning of the study. 7/8 participants who completed the screenings showed improvement (2-21%), with only one participant showing a negligible decrease (0.9%).

Impact of intervention on pre-PHV participants

As previously discussed in Chapter 5, it is suggested the greatest emphasis in physical training in youth athletes prior to the onset of puberty should be FMS training (Lloyd and Oliver, 2012). This aims to provide a solid athletic foundation needed to be able to deal with the complexity of sport specific movements later (Lloyd and Oliver, 2012).The findings of this study are in alignment with previous studies in other youth populations which the support the use of FMS interventions to produce improvements in movement competency and/or physical fitness performance (Liao and Li, 2017, Bodden et al., 2015, Song et al., 2014, Baron et al., 2020). Three of these studies reported significant change in a larger number of components assessed in their respective screenings and fitness test batteries (Liao and Li, 2017, Song et al., 2014, Baron et al., 2020)). Liao and Li (2017) demonstrated the superior outcomes ($p<0.01$) of a 12-week programme inclusive of functional movement corrective exercise and functional strength training on both movement quality and fitness measures when compared to a traditional strength training, but no ES were reported. The study by Song et al. (2014) reported significant change ($p<0.05$) in 5/7 components of the FMS total score after 8 and 12 weeks of intervention but had mixed effects on baseball performance (decreased pitching ball speed, but increased ball control and single leg stance time). Baron et al. (2020) achieved a 48.5% (p=<0.01) improvement in average FMS component scores (7/7), as well as small but significant improvement in speed measures (0.9-2.4%). Lastly, Bodden et al. (2015) having previously established a relationship between FMS movements and MMA training and performance, demonstrated that an 8-week FMS intervention increased total FMS scores at significant level ($p<0.006$) when compared to controls. However, the impact of these improvements on fitness performance was not assessed. All of the previous studies involved longer interventions (7-16 weeks), as well as higher frequency of training (3-4 times per week), whereas this study was only 6-weeks long and carried out twice a week, in line with minimum dose theory (Steib et al., 2017). Variation in methodology, different statistical approaches and lack of reporting of ES of the previous interventions make them difficult to directly compare to the findings of this study. However, is possible to suggest that increasing the length and frequency of the training programme may also yield greater changes in performance.

Variation in baseline competency appears to influence how quickly a player can make acute improvement in these fundamental movements. The player with lowest pre-test screening score (39/90) made the biggest improvement (16.7%) and the player with the highest pre-test score (63/90) made the smallest improvement (0.8%). In this example, it also aligns with results of previous chapters around the relationship between physical competency and performance, with the two players also holding the lowest and highest ranking respectively for their birth year. This supports the theory that a failure to grasp FMS may create a proficiency barrier precluding children conquering more complex skills (Gallahue and Donnelly, 2007, Oliver et al., 2013). Logically, the players with lower initial scores have greater scope for improvement, but at the same time need to be able to take on the information given when receiving coaching cues to make changes. For higher scoring players the use of the current scoring system in the modified AAA may also limit perceived improvement, as most components required a "perfect execution" for a player to move from a subjective 2/3 to a 3/3. Meaning that even if there was clear evidence of improvement in the movement patterns, if not perfect, the scoring may not be sensitive enough to highlight this and is a limitation of the current protocol. However, players in between these scores had a variation of responses between 0-15%, (and a single player showing a 6.5% decrease), which suggests that there are likely multiple factors at play. Including factors such as somatic maturation within the group, genetics, activity level, previous exposure to different sports and previous injuries which have all been previously shown to influence an athlete's physical competency (Myer et al., 2013).

The fitness components where participants made significant change were jumping (CMJ), throwing (backhand and overhead medicine ball throw) and endurance (Yo-yo Test). Perhaps these results could be expected, as acquisition of object control and locomotion skills, such as throwing, jumping and running form the backbone of FMS training and the programme designed for this study (Lloyd et al., 2013, Lloyd and Oliver, 2012). The results align with a meta-analyses of 19 previous studies in youth populations showed the majority of FMS interventions to have a large effect for overall gross motor proficiency, locomotor skill competency and a medium effect on object control competency (Morgan et al., 2013). Both the results of Chapter 4 and previous research has shown upper body power to be a key indicator of performance in this age group (Kramer et al., 2017b, Kramer et al., 2016a, Ulbricht et al., 2013, Ulbricht et al., 2015a). This appears to be the first study to note improvement in this area from a simple intervention of this duration. Although this will need further investigation, it provides initial evidence for introducing this type of training in players of this age. Given that the intervention uses minimal equipment and can be performed on court, it provides a low-cost option which can be widely available to most young players.

Impact of intervention on post-PHV Players

A key finding in this group was the significant change in overall screening score. As there is already an established link between screening score and injury severity in tennis players (Filipcic and Filipcic, 2019), it is useful to know that an intervention like this can make improvements and potentially reduce injury risk in a short period of time. Players in this group were also able to make significant improvements in overhead squat, a component which has potential to make notable changes in performance due to the physical qualities required to execute the movement well (Yildiz, 2018). In particular, the requirement in the squat for good mobility and stability in the ankle, knee and hip areas as well vertical force production ability, has been shown to correlate well to vertical jumping (Lockie et al.,2014, Lockie et al., 2015b). These qualities also correlate to more efficient dynamic movement, something which is particularly pertinent to a sport involving up to 1000 changes of direction (Yildiz, 2018, Fernandez-Fernandez et al., 2014b).

Significant improvement in lateral bound was noted, although only on the right side. This could be reflective of quicker rate of improvement on the dominant side or evidence of asymmetry in the lateral stability of young tennis players but requires further investigation in a larger sample to validate. This test was used due to the large presence of lateral movement within the sport, as a lateral bound requires both the ability to accelerate and decelerate laterally well to perform effectively(McKeown et al., 2014, Kovacs, 2009). In turn this is something which can dictate lateral change of direction speed and a factor shown to correlate strongly to playing level (Ulbricht et al.,2015a, Ulbricht et al., 2015b,Fett et al., 2017). For players with a low or training age of zero at this stage of maturation, FMS training would likely have to play a larger part than usual to ensure competency before loading or complexity in S&C training (Lloyd and Oliver, 2012). If the results of this study can be extrapolated further to wider populations, practitioners can take confidence that their programme will improve overall competency and in turn this may start to have a knock-on effect on performance.

Flexibility was the only physical or tennis parameter to show significant change. This is a positive finding for coaches working with players who have recently gone through PHV and struggling with muscular restriction. As it highlights that a short, low dose programme can be effective acutely, and aligns with existing recommendations around preventing injury via improving flexibility (Kibler and Safran, 2000). A lack of significant change in the other parameters does not necessarily mean the intervention was not suitable for this age group in terms improving fitness, as most players improved to a smaller extent in most measured parameters. However, it does raise some considerations around planning future programmes. Given the range of playing levels within this cohort it is possible that for those starting from a higher baseline competency that the programme did not provide a challenging enough stimulus for change, or the volume of training was not sufficient. All players had an S&C training age of 0, however overall training age responsible for the development of musculoskeletal health, FMS and overall health can be defined by accumulated time in both training programmes and sport-related activities (Myer et al., 2013). Meaning there is potential for a large range in general training age, and this was reflected in the range of pre-screening scores, with a 20-point difference between the highest and lowest scores. It is generally recommended that screening scores are used to individualise training programmes focusing on the individual's weakest link, which may be a more effective method, but this was not possible in a group-based training (Cook, 2010). Future studies should look to further personalise players FMS programmes in this age-group, as it is generally accepted that competency improves to some extent with maturity (Lloyd et al., 2015), players of this age may require more specificity to make significant change. On the same note, if changes in FMS are more subtle than in younger children who require more coaching, it may take longer to see a transfer of these improvements into fitness or tennis skill tests.

8.6.2 Limitations

The limitations in this study are largely linked to challenges of working with child and youth athletes. Variations in effort level, concentration, attendance and understanding of the training programme varied greatly and therefore likely impacted the results. As well as concentration and effort levels of the individual, as it was apparent some players took the testing sessions more seriously than others. The gross nature of the movement screening scoring criteria may also have been a limitation in the assessment of progress pre- and post-test. It is possible that the criteria was not sensitive enough to pick small changes occurring across such a short period of time, meaning that some players progression or regression may have been overlooked.

8.7 Practical Applications

The FMS intervention programme used in this study was able to make significant changes in the overall FMS competency in post-PHV players within 6-weeks. This aligns with previous FMS intervention studies but is the first to identify this in tennis players of this age. This is useful information given that if talented players are starting S&C at this age, they may be behind their international peers in terms of physical development (Fett et al., 2017). The results of this study suggest that physical competency can be improved in an on-court environment with minimal equipment, making it accessible for all players. Subjectively, despite overall improvement in screening scores the lack of significant change in pre-PHV group, may also be reflective of a few cognitive and psychosocial factors not measured in this study and something that should be considered in future studies in this age group. These are factors such as the ability to understand coaching cues, body awareness and peer pressure. In this cohort, pre-PHV players were able to make more significant changes in fitness parameters than screening scores as a result of the intervention, further support that focus on FMS training prior to puberty can provide foundational blocks for athletic performance.

8.8 Conclusion

Given the relationships established between movement competency and tennis performance demonstrated in Chapter 7, it appears that FMS training programmes such as the one used in this study (inclusive of both general fundamental movements and corrective exercises targeting underlying components enabling proficiency), would be a useful addition to the training methods utilised in this population. As one of a limited number of studies, future research would benefit from ascertaining if there is further improvement seen with increased frequency, duration and personalisation of this type of training programme to optimise time and performance enhancement.

Chapter 9 – The impact of a strength training intervention on the movement competency, physical fitness and tennis performance of junior tennis players aged 11-15 years old.

9.1 Preface

Chapter 5 indicated that NZ junior players had significantly lower training volumes than their international peers, in addition to starting S&C later in adolescence. The reason for these trends were not investigated in this thesis. However, ensuring S&C training is accessible for all NZ junior players in an ecologically valid manner can only help to change this narrative. The findings of Chapter 8 indicated that FMS competency could be significantly improved in an on-court, minimal-equipment environment across a 6-week period. Once an athlete has a solid foundation of FMS skills, strength development is vital, as it has been repeatedly highlighted as a key contributor to tennis performance in this age group (Chapters 4, 5 and 6). Therefore, this chapter aimed to determine the impact of a strength training intervention on physical and tennis performance.

9.2 Introduction

It is now well established that under the supervision of qualified personnel, children and youth athletes can successfully and safely participate in strength training, allowing them to benefit from the multiple health and performance benefits associated with this training modality (Lloyd et al., 2012a, Faigenbaum et al., 2009, Lillegard et al., 1997, Myer et al., 2013, Chaabene et al., 2020). Following LTAD paradigms, it is suggested that during adolescence athletes may gain most from this type of training in the 12-18 months following PHV, when endocrinological changes enable the rapid development of muscle mass (Lloyd and Oliver, 2012). Due to the multifaceted nature of strength development involving both neural and mechanical factors (Lloyd et al., 2012a) and the heightened level of neural plasticity prior to adolescence, it is widely accepted that age-appropriate strength training can induce improvements in prepubertal children as well (Lloyd et al.,2012a, Myer et al.,2013, Faigenbaum et al.,2009).

A small number of resistance training intervention studies have been presented in previous tennis literature, but these largely focused on adult populations (Kraemer et al., 2003, Kraemer et al., 2000, Niederbracht et al., 2008). To date the impact of strength training in junior tennis players is limited to four studies, all which focused their interventions on adolescent males aged 14-16 years old (Fernandez-Fernandez et al., 2013, Fernandez-Fernandez et al., 2014a, Sarabia et al., 2015, Behringer et al., 2013). As previously discussed, the serve is often considered the most important shot and subsequently was the main objective of two of the interventions (Behringer et al., 2013, Fernandez-Fernandez et al., 2013). These studies used different training methods; i) a comparison of plyometric training programme to a machine-based resistance training programme (Behringer et al., 2013) and ii) a programme focused on core strength, light resistance band training and flexibility versus a control group (Fernandez-Fernandez et al., 2013). Fernandez-Fernandez et al. (2013) found their 6-week programme to be an effective method of improving service velocity ($p=0.001$ $d=0.41$). Whereas Behringer et al. (2013) found only the plyometric training group to make significant changes in post-test service velocity ($p<0.05$), despite both the resistance training and plyometric training groups making significant strength improvements when compared to controls as measured by 10RM assessments ($p<0.05$). This largely corroborates with the results of studies in adult players using isokinetic strength training in the prevention of injury of the shoulder, as well as for serve/stroke performance enhancement (Ellenbecker et al., 1988, Mont et al., 1994). This is perhaps not surprising as isometric and isokinetic strength assessment of different joints have frequently shown a positive relationship to serve and stroke velocities in adult players (Mont et al., 1994, Ellenbecker et al., 1988).

The other two studies focused on physical improvements from the intervention also used two different methods (i) a non-failure strength programme including plyometric jumps and throws (Sarabia et al., 2015), ii) a combined explosive strength and interval training programme (Fernandez-Fernandez et al., 2014a)Both studies producing significant improvements in their chosen outcome measures. For Sarabia et al. (2015) this was evident in the parallel half squat (total reps, peak power and mean power; η^2 0.58-0.73), squat jump ($p = 0.002$; $\eta^2 = 0.54$), countermovement jump ($p = 0.041$; $\eta^2 = 0.34$) and side medicine ball throw ($p = 0.001$; $\eta^2 = 0.49$). In the study by (Fernandez-Fernandez et al., 2014a) significant improvements were seen in 10m sprint, countermovement jumps, as well as mean and best repeated sprint times ($p≤0.001$ ES: 0.3-0.8).

Although all the previous studies produced significant change in their outcome measures, therefore advocating strength training interventions in junior tennis for performance enhancement, the variation in methodology and assessments used makes them difficult to compare to one another. Using the results of 4 studies examining the effects in males aged 14-16 years old, is not sufficient data to allow evidence-based practice in the wider junior tennis population. It is evident there is a gap in the literature on the use of these interventions prior to the age of 14 and within female athletes. Subsequently, this study intended to address this by establishing the impact of a strength training intervention in players aged 10-15 years old of both genders. It aimed to provide some initial evidence around the efficacy of introducing a training programme of this nature players in this age group, which future research could build upon and investigate further.

9.3 Methods

9.3.1 Subjects

Twenty players (10 males and 10 females) aged 10-15 years participated in the study. Participant age and physical characteristics are presented in Table 9.1. Players volunteered to participate and were included if they described tennis as their main sport, played at least three times per week, were free from injury and did not participate in any form of structured strength and conditioning. Participant playing level varied significantly with respective age-group national rankings ranging from 1-100. Some of these participants had taken part in the previous training study and others were new volunteers to the training group. Biological maturity was determined using the Mirwald equation (Mirwald et al., 2002). For those who fell within the margin for possible error (± 0.6yrs from PHV), a secondary subjective assessment of physical appearance (non-invasive only) was made by the primary researcher to help minimise error in categorisation.

Table 9.1 Descriptive statistics of all subjects

	ALL	Pre-Peak Height Velocity	Post-Peak Height Velocity
N=20	2	14	6
Age (years)	12.3 ± 1.5	11.5 ± 1.2	13.9 ± 0.6
Height (cm)	153.5 ± 9.9	148.9 ± 8.2	164.8 ± 1.9
Weight (kg)	44.9 ± 9.6	40.1 ± 6.6	56.4 ± 4.0

9.3.2 Procedures

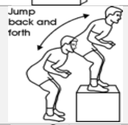
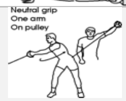
Testing

Pre and post-test testing sessions took place immediately before and after the 6-week intervention programme. Both testing and training sessions took place at the same indoor tennis facility on an indoor hard court. All participants completed the same physical testing battery and tennis skill tests as described in Chapter 7. The tests were completed in the following order: the modified AAA screening, physical testing battery (5m, 10m and 20m sprints, forehand and backhand agility, CMJ, SJ, forehand, backhand and overhead medicine ball throws, grip strength and yo-yo intermittent endurance test), followed by the serve velocity and accuracy test. The same modifications made in Chapter 8 to reduce the AAA Screening battery were used in this study.

Training

The six-week intervention programme consisted of two sixty-minute training sessions in the gym per week. To be included in the analyses participants had to attend at least 85% of the sessions. The training programme consisted of a 10-minute warm-up including a cardiovascular heart rate raiser (skipping/running or biking) followed by a series of dynamic mobility exercises listed in Table 9.2. This was followed by approximately 50 minutes of strength training, using bodyweight and external resistance training methods (see Table 9.2). Equipment was limited to that which could be made portable to take place on court or exchanged for something that could be transported to maintain ecological validity for the wider tennis community in NZ. Two strength and conditioning coaches ran each session in groups of 6-10, with loads for each exercise correctly assigned and adjusted when necessary. In alignment with recommendations for child and youth athletes' initial loads were selected based on the participant being able to complete all reps in the set with fatigue but no muscle failure (Faigenbaum et al.,1996). Sets of strength exercises consisted of 8-12 reps at an intensity of 7-8/10 RPE. Good technique was essential for prescription of additional load and was based on each individual athletes' physical competency, size and individual rating of perceived exercise (RPE).

Table 9.2 6-week strength intervention programme

STRENGTH PROGRAM									
				Week 1	**Week 2**	**Week 3**	**Week 4**	**Week 5**	**Week 6**
1.		GOBLET SQUAT	KETTLEBELLS	2X8	2x10	2x6	2x10	2x12	2x6
2.		SUPINE ROW	BW	2X8	2x10	2x6	2x10	2x12	2x6
3.		WIDE PRESS UP	BW	2X8	2x10	2x6	2x10	2x12	2x6
4. A		STEP UP	BW / WITH MED BALL/ DUMBELLS	2X8	2x10	2x6	2x10	2x12	2x6
4. B		BOX JUMP	BW	2x4	2x5	2x3	2x4	2x5	2x3
5.		CLOCK LUNGE	BAR	2x3 each side (9 lunges total ES)	2x4 each side (12 lunges total ES)	2x2 each side (6 lunges total ES)	2x4 each side (12 lunges total ES)	2x5 each side (15 lunges ES)	2x3 each side (9 lunges total ES)
6.		DOUBLE ARM CABLE ROTATION	CABLE/ RESISTANCE BANDS	2X8 each side	2x10 each side	2x6 each side	2x10 each side	2x12 each side	2x6 each side
7.		NORDIC LEAN	BW	2X8	2x10	2x6	2x10	2x12	2x6
8.		SINGLE ARM WOODCHOP	CABLE/ DUMBELLS	2X8 each side	2x10 each side	2x6 each side	2x10 each side	2x12 each side	2x6 each side

*BW= Bodyweight, ES=Each side

9.4 Statistics

As in the previous chapters the movement screening was scored by two independent raters who marked movements against the previously described template in Table 7.3, blinded to the scores of the other. Inter-rater agreement values quantified using intraclass ICC and CV were provided in Chapter 8. ICC estimates and their 95% confidence intervals were reported in Chapter 8. The reliability of the fitness test measures has been reported in previous chapters for similar cohorts and level of players (see Chapters 5 and 8).

Shapiro-Wilk was used to assess normality of data distribution, finding all data to be normally distributed. Once normality was established a paired samples t-test was used to compare pre-test and post-test means of all participants. Analyses were also completed in two separate maturity groups (pre-PHV and post-PHV). However, given that the participant cohort was predominantly of pre-PHV status (14 pre-PHV:6 post-PHV) interpretation of the results was focused on the analyses of the whole cohort. Significant changes in means were identified when $p \leq 0.05$. Effect size was calculated to describe the magnitude of the change using Hedges' g and this size was defined as in line with definitions of size of change (Fritz et al., 2012). The magnitude of change was considered as ≥ 0.2 small, ≥0.5 medium and ≥0.8 large (Fritz et al., 2012).Given that the data was normally distributed, Pearson's correlations were used to examine the relationship between change in physical fitness performance and change in movement competency performance. The same scale as used above to describe ES, was used to determine the strength of the relationships (≥ 0.2 small, ≥0.5 medium and ≥0.8 large) (Fritz et al., 2012).

9.5 Results

9.5.1 Compliance

Initially 22 players signed up to participate in the study. 2 players turned 16 years old during the study and therefore were considered too old for the analysis. The remaining 20 players reached the 85% threshold for compliance, attending sufficient training sessions and both pre and post-test sessions. However, 4 players were unable to complete the post-test movement screening due to timings with other external school commitments.

9.5.2 Fitness and Tennis Testing

Group means reflected overall improvement in all components with exception of grip strength on the dominant side (GSD). Significant change in means pre and post intervention were seen in all speed and agility measures, as well forehand medicine ball throw and Yo-Yo test (see Table

9.3). Effect sizes were found to be large for 5m (1.2) and 10m (0.8) sprint and backhand agility (0.8), medium for 20m (0.6), forehand agility (0.6) and Yo-Yo (0.6), and small for forehand medicine ball throw (0.3).

When analysed by gender groups, differences in response to the training intervention were observed in the number of variables in which significant change ($p=<0.05$) was achieved. Female players saw significant change in all speed and agility tests, forehand medicine ball throw and Yo-yo test, for a total of 7/16 components with significant changes. Male players also saw significant changes in speed tests, backhand agility and Yo-yo tests, but not in forehand agility or forehand medicine ball throws, therefore only demonstrating significant in 5/16 components. Effect sizes of the changes observed in the female players were medium (ES=0.48 forehand agility) and large (ES=0.88 forehand medicine ball throw).

No significant changes were observed in measures of tennis performance, with only minimal changes in means in both serve velocity and accuracy (see Table 9.4).

Table 9.3 Fitness Testing: Pre and Post-test group means and effect sizes.

	Pre-Peak Height Velocity				Post Peak Height Velocity				All Participants			
	Pre-test	Post-test			Pre-test	Post-test			Pre-test	Post-test		
Test	Mean ± SD	Mean ± SD	p	Hedges' g	Mean ± SD	Mean ± SD	p	Hedges' g	Mean ± SD	Mean ± SD	P	Hedges' g
Countermovement Jump (cm)	28.50 ± 5.50	29.50 ± 6.20	0.24	0.16	28.6 ± 3.90	28.4 ± 3.66	0.77	1.4	28.80 ± 5.10	29.3 ± 5.50	0.41	0.09
Squat Jump (cm)	27.30 ± 6.10	27.80 ± 5.70	0.51	0.08	26.6 ± 3.90	27.1 ± 3.20	0.64	0.7	27.30 ± 5.40	27.50 ± 4.90	0.744	0.04
5m Sprint (s)	1.22 ± 0.08	1.15 ± 0.08	**<0.01**	0.88	1.21 ± 0.03	1.11 ± 0.05	**0.03**	0.6	1.22 ±0.07	1.13 ± 0.07	**<0.01**	1.2
10m Sprint (s)	2.12 ± 0.10	2.04 ± 0.10	**<0.01**	0.8	2. 06 ± 0.05	1.95 ± 0.06	**0.04**	2.0	2.09 ± 0.12	2.00 ±0.12	**<0.01**	0.8
20m Sprint (s)	3.79 ± 0.30	3.66 ± 0.20	**<0.01**	0.54	3.62 ± 0.09	3.47 ± 0.10	**0.06**	2.2	3.72 ± 0.25	3.58 ± 0.22	**<0.01**	0.6
Forehand Agility (s)	2.54 ± 0.10	2.47 ± 0.16	**0.02**	0.54	2.49 ± 0.09	2.37 ± 0.11	0.22	1.2	2.52 ±0.13	2.43 ± 0.15	**0.01**	0.6
Backhand Agility (s)	2.62 ± 0.10	2.53 ± 0.10	**0.01**	0.90	2.54 ± 0.08	2.42 ± 0.06	0.01	0.6	2.58 ± 0.12	2.49 ± 0.12	**<0.01**	0.8
Forehand Medicine Ball throw (m)	9.30 ± 2.00	9.60 ± 2.40	0.09	0.13	10.50 ± 1.80	11.40 ± 0.14	0.39	0.7	9.50 ± 1.90	10.10 ± 2.20	**0.03**	0.3
Backhand Medicine Ball throw (m)	8.80 ± 1.60	9.00 ± 2.00	0.37	0.11	10.40 ± 0.61	10.70 ± 0.74	0.45	1.0	9.1 ± 1.60	9.30 ± 1.90	0.15	0.1
Overhead Medicine Ball Throw (m)	7.55 ± 1.20	7.66 ± 1.60	0.46	0.07	9.4 ±1.50	9.40 ± 2.00	1.0	8.6	8.00 ± 1.50	8.20 ± 1.80	0.37	0.1
Yo-Yo Distance (m)	690 ± 362	865 ± 349	**0.04**	0.49	750 ± 68	960 ± 1.42	0.10	1.8	768 ± 332	988 ± 357	**<0.01**	0.6
Grip strength Dominant (kg)	25.52 ± 6.50	23.9 ± 7.40	**0.04**	0.22	32.6 ±1.70	33.60 ± 2.30	0.40	0.7	27.90 ± 6.70	27.10 ± 7.9	0.21	0.10
Grip Strength Non-Dominant (kg)	20.26 ± 4.60	19.99 ± 6.40	0.61	0.05	28.3 ± 1.20	29.20 ± 3.20	0.32	0.7	22.90 ± 5.60	23.1 ±7.20	0.88	0.03
Sit and Reach (cm)	25.5 ± 9.40	27.5 ± 9.00	0.06	0.21	34.8 ± 11.10	35.00 ± 10.20	079	0.01	28.9 ± 10.40	29.90 ± 9.60	0.20	0.09

*__Bold__ font denotes significant change in mean

Table 9.4 Serve Performance Testing: Pre and Post group means and effect sizes.

Test	Pre-Peak Height Velocity				Post-Peak Height Velocity				All Participants			
	Pre-test	Post-test			Pre-test	Post-test			Pre-test	Post-test		
	Mean ± SD	Mean ± SD	P	Hedges' g	Mean ± SD	Mean ± SD	P	Hedges' g	Mean ± SD	Mean ± SD	P	Hedges' g
Peak Serve Velocity (kmph)	115.40 ± 20.00	117.90 ± 13.90	0.40	0.14	127.00 ± 9.10	125.10 ± 12.40	0.54	0.17	119.0 ± 17.90	120.10 ± 13.50	0.63	0.32
Mean Serve Velocity (kmph)	106.00 ± 18.60	110.40 ±13.10	0.10	0.27	121.00 ± 9.50	119.00 ± 13.30	0.51	0.17	110.70 ± 17.60	113.10 ± 13.40	0.25	0.06
Serve Accuracy (Score out of 24)	6.30 ± 3.10	6.60 ± 3.20	0.74	0.09	7.60 ± 2.00	6.80 ± 2.90	0.38	0.32	6.80 ± 2.80	6.70 ± 3.00	0.85	0.03

***Bold** font denotes significant change in mean

9.5.3 Movement Screening

Pre and post-test means, and ES of the movement screening are reported in Table 9.6. Improvement was seen in all individual tests and total score; this was statistically significant ($p<0.05$) in all but the forward hops. ES were found to be medium in left walking lunge (0.71), right lateral bound), push up (0.76) and prone hold (0.64), and large in overhead squat (0.83), right walking lunge) 1.1, LB (left) 0.85 and total score (1.0).

Like the physical fitness testing results, analysis by gender showed female players to make significant change in more components than male players (7/10 components vs 5/10 components). Most ES observed were large in magnitude, except for mean change in prone hold scores in females which was medium (See Table 9.5).

As shown in Table 9.7, no significant correlations were found between fitness scores which had seen significant change post-test and any components of the movement competency screen.

Table 9.5 Gender comparison of significant changes in mean movement screening scores paired t-test p values and effect sizes

	Females		Males	
	p	ES	p	ES
Overhead Squat	0.04	0.90	0.15	1.35
Walking Lunge Left	0.05	0.81	0.01	1.56
Walking Lunge Right	<0.01	2.20	0.02	1.55
Forward Hop Left	0.02	1.25	0.46	n/a
Push up	0.01	2.45	0.47	n/a
Prone Hold	0.05	0.54	0.03	0.89
Total	0.03	1.61	0.02	1.60

Table 9.6 Modified AAA Screening: Pre and Post intervention group means and effect sizes.

	Pre-Peak Height Velocity				Post-Peak Height Velocity				All Participants			
	Pre-test	Post-test		Hedges' g	Pre-test	Post-test		Hedges' g	Pre-test	Post-test		Hedges' g
	Mean ± SD	Mean ± SD	P		Mean ± SD	Mean ± SD	P		Mean ± SD	Mean ± SD	P	
Overhead Squat	5.5 ± 1.6	6.6 ± 1.3	**0.02**	0.75	6.2. ± 1.9	8.2 ± 0.9	**0.05**	1.2	5.7 ± 1.6	7.0 ± 1.3	**0.01**	0.83
Walking Lunge Left	5.6 ± 1.9	7.1 ± 1.4	**0.04**	0.83	7.1 ± 1.5	7.8 ± 1.3	0.10	0.49	6.1 ± 1.9	7.3 ± 1.4	**0.01**	0.71
Walking Lunge Right	5.8 ± 1.5	7.3 ± 1.5	**0.03**	1.00	6.1 ± 1.0	7.7 ± 1.3	**0.01**	1.30	5.9 ±1.4	7.5 ±1.4	**<0.01**	1.10
Lateral Bound Left	5.8 ± 1.5	7.0 ± 1.2	0.06	0.85	6.1 ± 0.8	7.7 ± 1.9	0.17	1.14	5.9 ± 1.4	7.1 ± 1.4	**0.03**	0.85
Lateral Bound Right	5.9 ± 1.6	6.9 ± 1.5	0.10	0.64	6.1± 0.9	7.9 ± 1.9	0.17	1.2	5.9 ± 1.4	7.1 ± 1.6	**0.03**	0.79
Forward Hop Left	5.5 ± 1.3	5.7 ± 1.6	0.70	0.15	6.0 ± 04	7.1 ± 1.0	0.14	1.4	5.6 ± 1.2	6.1 ±1.5	0.31	0.37
Forward Hop Right	5.8 ± 1.3	6.5 ± 1.6	0.12	0.48	5.9 ± 1.0	6.3 ± 1.7	0.35	0.28	5.8 ± 1.4	6.4 ± 1.6	0.06	0.39
Push Up	5.8 ± 1.3	7.1 ± 2.6	0.14	0.65	6.8 ± 0.3	8.5 ± 1.6	**0.04**	4.1	6.0 ± 1.2	7.4 ± 2.3	**0.05**	0.76
Prone Hold	5.8 ± 1.7	6.9 ± 1.6	**0.03**	0.66	6.4 ± 1.1	7.5 ± 1.2	0.09	0.96	6.0 ± 1.5	7.1 ± 1.5	**0.05**	0.64
Total Score	50.7 ±10.1	61.3 ± 9.9	**<0.01**	1.10	57.4 ± 7.6	66.9 ± 13.2	0.08	0.87	52.4 ± 9.8	62.7 ± 11.0	**<0.01**	1.00

***Bold** font denotes significant change in mean

Table 9.7 Pearson's Correlation coefficients between significant changes in performance and change in movement competency.

	All Participants						
	5m	10m	20m	FHAG	BHAG	FHMB	Yo-yo
Overhead Squat	-0.02	-0.04	0.04	0.36	0.30	-0.30	0.31
Walking Lunge Left	0.03	0.11	0.35	-0.14	-0.07	-0.15	0.06
Walking Lunge Right	0.03	0.04	0.25	-0.07	-0.06	-0.18	-0.07
Lateral bound Left	0.10	-0.12	-0.15	-0.26	-0.45	-0.03	0.33
Lateral bound Right	0.08	-0.10	-0.16	-0.10	-0.46	0.15	0.29
Forward hop Left	-0.42	-0.45	-0.43	-0.34	-0.48	0.33	-0.05
Forward Hop Right	-0.38	-0.33	-0.27	-0.32	-0.24	0.08	-0.15
Push up	0.20	0.14	0.17	-0.17	0.05	0.01	-0.36
Prone hold	0.38	0.40	0.49	-0.09	0.11	-0.27	-0.10
Total Score	0.06	-0.01	0.10	0.30	0.29	-0.01	0.13

9.6 Discussion

The multifaceted benefits of strength training even prior to puberty is well established (Lloyd and Oliver, 2012, Faigenbaum et al., 2009, Lillegard et al., 1997, Myer et al., 2013). Therefore, it is assumed that this type of intervention would also be beneficial for the enhancement of physical competency and performance of junior tennis players. However, given there is a paucity of previous intervention research substantiating this for tennis players in early adolescence and particularly in female athletes, the main objective of this study was to ascertain the impact of a strength training intervention on junior tennis players of both genders age 10-15 years old. The main findings of this study demonstrated that this type of intervention was able to make significant change to players fitness scores and physical competency scores in 6-weeks. However, this did not transfer to significant improvement in tennis performance in terms of serve accuracy of execution or velocity.

The findings of this study also imply that female players of this age may see more improvement from this type of intervention in the outcome measure categories assessed in the thesis (movement competency and physical fitness performance) than males. As there is no previous research in adolescent female players, it is difficult to draw conclusions on why this may be and could be related to several different reasons (e.g., different baseline level of fitness, increased mental maturity allowing better application of coaching information received, timing of PHV). Regardless, the difference in responses between genders should be a topic considered in future research, to ascertain if each gender would benefit from different approaches at the same age and not assume a one-size fits all approach is best practice when it comes to training junior tennis players.

9.6.1 Impact of intervention on fitness testing measures

The results indicated the intervention had most notable influence on running performance, including linear sprint, change of direction speed and endurance running, reflected in the large to very large changes in sprint times, agility times and Yo-Yo endurance test (distance covered) (See Table 9.3). This aligns with meta-analyses of previous research that has provided evidence that strength training in youth athletes has the potential to influence muscular strength, power and endurance, agility, balance, stability, coordination, and speed of movement in youth athletes(Harries et al., 2012, Lesinski et al., 2016, Granacher et al., 2016).

A meta-analysis of 34 studies investigating the effects of resistance training on athletic performance of youth aged 13.2 ± 3.1 years found moderate effect sizes on running times (ES=0.54, 95% CI 0.34–0.74) (Behringer et al., 2013, Collins et al., 2019) smaller than seen in this study (5m: ES-1.2, 10m: ES-0.8, 20m:ES-0.6). However, it was also noted that greater gains were seen in younger and non-athletes, which is not dissimilar to this cohort which had a low or no S&C training age and had a greater number of pre-PHV players, possibly explaining the larger effect sizes seen in this study (Behringer et al., 2013).

Most intervention studies in other sports saw concurrent improvement in lower limb strength and speed measures, meaning increased force production ability may explain their increased sprint times (Lockie et al., 2016, Styles et al., 2016, Rodríguez-Rosell et al., 2017). This was not the case in this study and there are number of possible reasons for this. Firstly, only indirect measures of lower limb strength were used as an outcome measure (SJ and CMJ). The coordination element of jumping may be a limiting factor in understanding genuine improvements in strength in this cohort, especially whilst some are not completely technically sound and/or growing. Due to high neural demand of jumping, previous interventions seeking to improve squat jump height have concluded that S&C coaches may be better served initially focusing more on plyometric training in pre-PHV athletes and a combination of strength and plyometric training in post-PHV to enable the greatest adaptations (Lloyd et al., 2012b). Although the programme followed in this intervention was inclusive of a plyometric exercise, this was perhaps not a large enough stimulus to elicit significant change.

It is well documented that speed and change of direction speed (referred to as agility in this thesis) is not only dependent on force production, but several other factors including stride length and frequency, technique, coordination, balance and several other fundamental movement skills (Lloyd et al., 2013, Meyers et al., 2017). Given that the programme took a movement quality over quantity (load lifted) approach to carrying out the training programme, it is possible that improvement was acquired through development of skills required for sound execution of the basic FMS making up the training programme (lunge, squat, jump, push, pull, rotate). This is in agreement with a previous intervention study in which the protocol focused on multiple components of FMS (neuromuscular strength, dynamic balance, jump training etc), with the authors observing large-moderate effect sizes on speed, agility single balance and abdominal endurance(Barber-Westin et al., 2016, Barber-Westin et al., 2010). Likewise, a more recent study found a protocol aimed at improving the performance of movement, not the performance of muscles in children had superior influence on performance outcomes (including speed and agility) (Yildiz et al., 2019).

9.6.2 Impact of intervention on Tennis Skill

In contrast to previous research there was no significant change in either the velocity or accuracy of the serve (Behringer et al., 2013, Fernandez-Fernandez et al., 2013). The reasons behind this apparent lack of transfer of either the fitness or physical competency improvements are likely multifaceted. The tennis serve is a complex skill involving coordination of the whole kinetic chain (Reid and Schneiker, 2008), there is often a time lag for any improvement within the process to become autonomous and translate into the execution of the skill (Reid et al., 2007a). It is possible that having the post-test session immediately after completion of the intervention, transfer of physical change to the skill had not yet occurred. Also, it could be speculated that given the age of the participants it is possible that some may not be at a stage of complete mastery of the skill, meaning technique execution is not consistent and therefore not sensitive enough to small change. Secondly, the successful training programmes in both previous studies included weighted throws and shoulder specific exercises (Behringer et al., 2013, Fernandez-Fernandez et al., 2013). It has been shown the probability of transfer is higher with exercises that are similar to the performance measure, also known principle of training specificity such as contraction type, contraction velocity, joint angles, and movement pattern (Young, 2006, Haff, 2015) lack of specificity to achieve that goal may be a limitation of the programme used, but it was not the primary focus of the intervention. However, it is something to consider for coaches to consider in their programming if improvement of the serve is a priority outcome of the intervention.

9.6.3 Impact of intervention on movement screening scores

The results demonstrated that the strength training intervention was able to significantly improve physical competency scores in nearly all components and total score. All ES were large to very large (ES=0.6-1.1) (See Table 9.6). This is in alignment with interventions in other sports who have sought to improve screening scores (as assessed by FMS™) through strength training interventions (Sawczyn, 2020, Dimundo and Linton, 2018, Bennett et al., 2019). Part of the LTAD paradigm maintains that the ability to perform athletic movements with sound technique should lead to more efficient force transmission within dynamic tasks and help stability and alignment in more open skills (Lloyd et al., 2015). Although these improvements in movement quality did not translate to acute performance in tennis skill execution, this may not be cause for concern in terms of the effectiveness of this type of training in this age group. As well as the lag between physical change to skill transfer discussed in the previous section, the results of Chapter 6 found there to be no significant relationship between AAA scores and serve performance measures in pre-PHV players. However, a moderate correlation was seen in post-PHV players, who should be further along the skill acquisition ladder in terms of technique and closer the autonomous stage of mastery, meaning they may be better placed to implement any physical improvements. As this cohort predominantly consisted of pre-PHV players, this possibly explains a lack of overall significant change in the group. Further research could look to investigate this in larger groups at both stages of maturation to clarify this.

Secondly, S&C practitioners should not overlook the existing relationship between AAA scores and ranking established in Chapter 6, suggesting better players had better movement competency scores. This relationship may be a more critical finding for the longitudinal tennis success of junior players and indeed important information for S&C coaches in tennis. The finding that this strength training intervention with strong emphasis on correct technique as used in this study can concurrently improve FMS scores and fitness testing scores, may be beneficial for exercise prescription for junior tennis players. Although, it should be acknowledged that the improvements in movement quality in this untrained cohort may be larger than in more experienced athletes due to a learning effect. Limitations aside, these results are the first indicator of a successful method of simultaneously improving both speed, agility and endurance measures and FMS scores in this age group, all of which have been showed to contribute to tennis performance (ranking). The lack of physical training time due to heavy training and competitive schedules has been previously discussed in Chapter 3, meaning best practice may mean using interventions that optimise limited training time for that stage of maturation (Murphy et al., 2013). Subsequently, this intervention may be particularly useful for those working with time-poor players or those late to start their S&C training.

9.6.4 Limitations

The main limitation of this study is the lack of control group, which could have provided an objective measure of how much of the observed changes were due to learning effect in an untrained cohort. At minimum it could have identified whether improvement came from technical instruction for screening alone or due to the technical education during the training programme, something which was noted in a similar intervention in middle distance running (Dimundo and Linton, 2018). Future research would benefit from using larger samples which would allow for a control group for comparison. Limitations associated with working with youth as previously discussed in Chapter 7 and 8, remain present for this study.

9.7 Practical applications

The study presented an example of a 6-week strength programme intervention shown to be an effective way of facilitating improvements in the physicality of young tennis players aged 11-15 years old. This programme could be particularly beneficial for S&C practitioners seeking to achieve concurrent improvements in both FMS and fitness components of players of this age group. As with the intervention used in Chapter 8, this is especially pertinent for those working with those starting S&C later with a poor of FMS foundation or seeking to compete internationally from the age of 13, leaving limited time for longer physical development blocks. It should be acknowledged that even for non-elite players strength training will not be the only modality of training in place at the time, as tennis training sessions may contain variants of plyometrics, sprint training and endurance training potentially influencing physical development.

9.8 Conclusion

This study provides further support for the use of strength training within this population for both genders, meanwhile acknowledging it is one of only a few studies to examine the topic meaning there is significant scope to build upon these findings. It also identified the benefits of using an ecologically valid strength training protocol that focused on movement quality as opposed to load, capable of improving physical fitness performance and movement competency concurrently with minimal equipment. Subsequently, meaning it could be delivered in an on-court or gym environment, extending application to wider portion of the tennis community, to those perhaps lacking access to a gym or resistance-training methods requiring specific equipment.

Chapter 10 – Summary, practical applications and future research directions

10.1 Summary of findings

There has been significant development in the field of S&C regarding the athletic development of youth athletes in recent years (Lloyd et al., 2012a, Lloyd and Oliver, 2012, Faigenbaum et al., 2009, Faigenbaum and Myer, 2010, Ford et al., 2011, Till et al., 2013). Despite the worldwide popularity of tennis, only limited S&C research has been conducted in junior tennis. Therefore, this thesis was able to provide some answers commonly posed by S&C practitioners working in tennis. Descriptive studies have started identifying the presence of specific physical traits correlating to junior tennis performance, as well as the influence of growth and maturation. This has created a foundation of data currently underpinning our understanding of the athletic training requirements of junior tennis players.

Overall, tennis research and recommendations from National federations align with the principles presented in the LTAD paradigms (Reid et al., 2003, Reid and Schneiker, 2008). FMS development is well established as a key part of these plans during childhood and early adolescence, consequently multiple National and international tennis federations advocate the use of movement competency screenings as an assessment and monitoring tool for top players (Reid et al., 2003, Fernandez-Fernandez et al., 2014b). Yet the literature review conducted in Chapter 2 highlighted that their use has not been substantiated with scientific evidence regarding validity or reliability in tennis or how screening results correlate to performance.

Furthermore, there is little empirical data on application of the training principles recommended for paediatric athletic development impact on the subsequent progress of tennis players' junior career. National federation guidelines often recommend high volumes of tennis training and heavy competitive schedule from an early age, as they appear to be requirements for reaching pinnacles of junior tennis success. Early indications suggest a significant relationship between training volumes and ranking, but this is based on limited data from elite junior populations (Ulbricht et al., 2015a, Fett et al., 2015, Fett et al., 2017). Busy schedules have increasingly meant studies in this population reporting a lack of available time for physical development and a need for a time-efficient individualised approach to S&C programming to maximise athletic potential (Ulbricht et al., 2013, Ferrauti et al., 2018, Fernandez-Fernandez et al., 2014b)Despite this, the second literature review in Chapter 3 revealed a minimal number of S&C interventions have been conducted in junior tennis players. Particularly lacking were studies of female players and those under the age of 14. It is apparent that this dearth of experimental evidence creates a lack of data on what type of training protocols may be most effective in improving physical qualities leading to enhanced tennis performance.

Based on synthesis of the information collated in both reviews, the overarching aim of this thesis was to gain better understanding of the factors influencing athletic development of junior tennis players between the ages of 10 -14 years old. Given the limitations found in literature and in partnership with research questions from Tennis NZ, this thesis set out to answer several questions and found the following:

10.1.1 What are the physical fitness, growth and anthropometric characteristics of New Zealand Junior tennis players and their relationship to tennis performance? (Chapter 4)

A cross-sectional analysis of 110 players competing in the U12 and U14 National Championships and a lower-grade event held concurrently, was used to examine the physical fitness, maturation and anthropometry characteristics of New Zealand's elite and sub-elite players. The key findings of this analysis were:

Physical Fitness Characteristics

1. Upper body strength and power qualities have a significant role in tennis performance (national ranking) of U14 players.
2. In female players, speed and agility also correlated to ranking, but was not the case in male players.
3. Large correlations were observed between serve velocity and ranking in all groups, apart from U12 males where a moderate correlation between serve accuracy was seen.

Growth and Maturation

1. Biological age appeared to be the best predictor of physical size within all groups, with the exception U14 females. It is theorised this is due to this group being the most homogeneous with nearly all players being post-PHV. Instead, predicted age at peak height velocity had larger correlations in this group, implicating the younger the player was when they reached PHV the bigger (taller and heavier) they were more likely to be.
2. The same variables for the respective groups had the highest correlations to physical fitness variables. Significant relationships were established between upper body strength (grip strength) and upper body power (overhead medicine ball throw) in all 4 groups. The same measure also provided the largest correlation to 20m speed in U14 players, as well as forehand agility and 5m speed in females.

3. Biological age had the strongest correlation to serve velocity in all male players and U12 females. The lack of correlation in U14 female group may be due to homogeneity in maturation within as previously noted.
4. Chronological age had the greatest correlation to National ranking suggesting the older the player was within their age-group, the higher their ranking was likely to be. U12 females were the exception, although there was a moderate association between sitting height and ranking but no other measure of maturation.

Relative Age Effect

1. Overall, the presence of relative age effect was found to be similar within this population as has been reported in other studies, with a greater representation of players born within the first half of the year.
2. In this cohort, this was more apparent in female players and prevalence increased with age and playing level.
3. When male players were separated by playing level the opposite trend was observed with over 70% born in the second half of the year in Tier 1 players.
4. Older females consistently outperformed younger players in physical fitness performance at U12 but not at U14, although this was not statistically significant.
5. Ranking was the only significant difference between 1st and 2nd halves of the year at U14 females and weight the only significant variable at U12.
6. The difference in physical fitness performance between halves of the year was less clear in male players of both age groups. Older players at U14 only demonstrated statistically significant superiority in squat jump, despite significant difference in all anthropometry and maturation measures.
7. In U12 male players no significant differences were observed in physical performance between halves of the year. In terms of maturation factor, those born in the second half of the year were found to have significantly earlier predicted age of PHV (APHV). This suggests that stage of maturation may be more equal than chronological age suggests and explain the lack of variance in performance variables.

10.1.2 What are the training characteristics of New Zealand junior tennis players and their relationship to tennis performance? (Chapter 5)

The second study identified the current practices of NZ tennis players in comparison to previous literature and other National federation guidelines. It was hypothesised that one of the possible causes for a lack of singles success in recent years, may be partly due to a significant difference in training volumes when compared to other developed nations. Chapter 4 demonstrated that trends in physical fitness characteristics, anthropometry and maturation were not dissimilar to those reported by more successful tennis nations. Therefore, this raised the question of whether the lack of singles success could be partly due to insufficient training programmes. Analysis of 98 tennis players revealed the following:

1. Tennis training volumes of the total cohort aligned with the lower end of published data and recommendations at U12. However, by U14 mean values of the participants were distinctly lower when compared to international peers.
2. When analysed by playing level, elite players did have similar tennis volumes to previous research and National federation guidelines, but insufficient physical training (inclusive of other sports at U12) and total training volumes.
3. Male players had higher levels of participation in other sports in both age-groups, as well as higher weekly volumes of training for other sports. This may compensate to an extent for the lack of specific physical fitness training seen within both age-groups and explain the lack of correlation with ranking and training volumes.
4. Female players appear to specialise earlier with lower participation in both age-groups and those that do train for other sports do so less frequently than males.
5. Of those participating in S&C, only around 40% do so with a specific qualified coach the remainder do so with the assistance of a tennis coach, parent or are self-led.

10.1.3 What is the longitudinal impact on physical development for elite New Zealand players receiving differing levels of funding across 4-years? (Chapter 6)

Chapters 2 and 3 demonstrated that very little longitudinal research has been conducted in junior tennis players. Having profiled the training characteristics of New Zealand players in Chapter 5, the next study analysed the developmental trajectories of players following different training programmes. The key objective being to note any discernible differences between training characteristics (frequency, volume, support etc) and physical development over time. The key findings of this analysis were:

1. The players of both genders that reported the highest volume of S&C at age 12 or prior to first assessment had the most well-rounded athletic profiles, but also had the highest tennis training volume.
2. Results suggested a positive relationship between physical performance outcomes and the level of structure and supervision of a players S&C programme received throughout the 4-years.

3. Players who received remote programming but completed sessions without professional supervision, saw the least progress in physical development and presented the same weaknesses at age 11 and 15 years.
4. Aligning with results of similar studies in other sports, individual trajectories reaffirmed that development is not linear, and progress does not necessarily happen concurrently for multiple components.

10.1.4 What is the relationship between movement competency and tennis performance of junior tennis players? (Chapter 7)

Chapters 4 and 5 was able to build a detailed picture of the current of the New Zealand tennis scene, establishing that players exhibited similar physical trends to international counterparts but trained considerably less overall. Longitudinal analysis in Chapter 6 provided primary support of the benefits of structured, consistent S&C training throughout adolescence on physical development, when compared to more informal training programmes. The next chapter shifted the focus into investigation of more practical constructs which are currently under researched, knowing that the practical implications resulting from these studies could be applied to both the New Zealand and wider junior tennis population. The first of these constructs being examination of the relationship between movement competency with physical fitness and tennis performance, as to the authors knowledge this had not been done previously at the time of data collection. The AAA (McKeown et al., 2014)was used as a screening tool of fundamental movement skills in 40 players age 10-15 years old and showed:

1. The AAA has good inter-rater reliability.
2. The AAA can be carried out in any environment with minimal equipment therefore supporting use of it as an ecologically valid assessment tool.
3. Total score showed a large negative relationship to ranking (r=-0.63), which did not differ significantly with maturity. Indicating the higher the total score the lower (better) the ranking of the player within their age group.
4. Analysis within maturity groups showed pre-PHV players to have larger correlations to ranking on all measured parameters apart from single leg squat which was only significant post-PHV.
5. Analysis by playing level found elite players (>10) were found to have superior FMS screening scores than sub-elite players, the difference was significant in 11/15 measured parameters with medium - large ES (0.66-1.33).
6. A moderate relationship between screening scores and serve velocity was observed in post-PHV players but not pre-PHV.

7. Multiple associations between screening component scores and total scores with physical fitness qualities were identified.
8. In agreement with the correlations to tennis performance (Chapter 4), the physical variables with the greatest correlation to screening components and total score were agility, upper body strength and power.
9. The Yo-Yo intermittent endurance test had the highest number of significant correlations to screening scores, suggesting that aerobic fitness of the individual contributes to their overall movement competency.
10. Hopping and bounding were the two screening components most frequently significantly correlated to fitness performance variables suggesting that dynamic, unilateral stability and balance, may be key fundamental movement components enabling physical and tennis components.

10.1.5 What is the impact of a 6-week FMS training intervention on movement competency, fitness and tennis performance of junior tennis players aged 10-15 years old? (Chapter 8)

The results of Chapter 7, strongly supported a link between FMS competency and an athlete's ability to play tennis, giving merit to assessing this as part of understanding the exercise prescription requirements for junior tennis players. While it is acknowledged that as the first study of its kind it requires further verification, it did potentially reinforce the positive impact of having a solid movement foundation on sporting performance. Due to the lack of S&C interventions trialled in this population, the next step in this thesis was to examine the acute effects of an FMS training protocol. Following a 6-week intervention the following conclusions were made:

1. Noticeably different responses to the protocol were seen in each maturity group, reinforcing the need to consider the stage of maturation of the athlete during exercise prescription not just chronological age.
2. The movement screening scores of pre-PHV players improved but not statistically significantly. However, this did translate to enhanced performance in lower and upper body power, as well as endurance.
3. Post-PHV players made significant changes in total screening score and three movement components, concurrent enhanced physical fitness scores were noted but only significantly in flexibility.
4. These results provide some support for the interrelationships between movement competency and physical fitness performance.

Additionally, the evidence that the intervention positively impacted both competency and performance in physical fitness parameters, providing validation for the use of a protocol focused purely on development of FMS in this age-group.

10.1.6 What is the impact of a strength training intervention on the movement competency, fitness and tennis performance of junior tennis players aged 10-15years old? (Chapter 9)

A natural progression in the LTAD plan of a young athlete is to evolve training to allow for more load and complexity once physical competency has reached an adequate level (Lloyd and Oliver, 2012). The protocol used in Chapter 8 highlighted that in players with no formal S&C experience, a 6-week FMS training protocol was sufficient stimulus to make positive change not only in movement competency but in physical fitness performance. The next chapter sought to identify if the same can be achieved through participation in a strength training protocol that maintained focus on quality of movement and required minimal equipment. This would mean relevant findings could be applied to the wider tennis population and not just those with access to specialist populations. The key findings were:

1. Concurrent improvement in fitness and movement competency were achieved through participation in this type of strength training.
2. Large ES were observed for all components and total scores in movement screening (0.64-1.10) except for hopping.
3. The largest changes in physical fitness performance were noted in speed, agility and endurance.

10.2 Limitations of Research

Most of the limitations in this thesis are related to some of the complexities of working with youth athletes:

1. Youth athletes often have busy schedules with school, tennis training, other sports training and other commitments. In each study there were cases where players missed a testing session or components of testing for a variety of reasons, e.g., leaving session early for school/other commitment, sickness, parent travel issues. This resulted in missing data and/or exclusion from analysis in the study due to not meeting the minimum 85% attendance.
2. It was difficult to find convenient times for both testing and training sessions. The age of the participants meant that they were also dependent on parent availability to provide

transport to and from the session. This no doubt contributed to the limited sample sizes of the intervention studies.

3. This thesis could be criticised for the lack of control groups used in Chapters 8 and 9, although this was of course considered, it was not possible to carry out for both ethical and logistical reasons. Ethically, I was recruiting untrained players to participate in training interventions and there was not sufficient interest from those not participating to complete the pre and post-test sessions only to act as controls. Secondly, a crossover design was considered but due to logistical reasons previously mentioned 6 different time slots had to be offered to enable all players to make 2 sessions per week required. Consequently, each session had different combination of players attending and therefore it was not straightforward to split into two groups.
4. Lastly, although not measurable it was evident that there was variation in effort as youth athletes do not always comprehend the serious nature of research. This was observed in both training and testing situations which may have impacted results. This behaviour may have arisen for several reasons such as conforming to peer pressure, fatigue from other sources or lack of motivation, and is largely uncontrollable. In extreme cases where it was mutually agreed by more than one coach supervising the testing sessions, that the player was not sufficiently trying they were removed from the analysis.

10.3 Practical Applications

In establishing the physical and training characteristics of New Zealand juniors in the descriptive studies of Chapters 4 - 6, this thesis has provided evidence for factors which strongly influence tennis performance. These practical applications are relevant to tennis and S&C coaches alike.

Evidence-based recommendations for S&C training priorities and training volumes

Chapter 4: Training priorities

- Consider a particular focus on training methods designed to improve upper body and strength as these qualities were found to be particularly relevant at U12 and U14 ranking, which is in agreement with previous research in older adolescents (Ulbricht et al., 2015a).
- Female players may require additional focus on development of speed and agility based on significance of their relationship to ranking. Previous research has highlighted the superior performance of elite female players in comparison to sub elite in these qualities (Kramer et al., 2016a). It may be logical to assume that improving these qualities and maintaining them should be a physical priority to facilitate tennis performance in female players.

- Serve velocity had the most significant influence on ranking from a young age. Increasing velocities present in professional tennis suggests this remains a key element of performance at professional level. Tennis coaches and S&C coaches may benefit from considering the following:
    - Timing of serve practice within training session: Literature on skill acquisition shows that motor learning was more effective under non-fatigued conditions (Barnett et al., 1973). Therefore, it is recommended that this takes place earlier in training or spread throughout the session to maximise technical skill development.
    - From a S&C perspective, inclusion of upper body strength and power development from the age of 10 years old should be considered as these qualities were shown to be particularly pertinent to serve velocity in nearly all age groups and across both genders.

Chapter 5: Training frequency

- Consider training volume prescription, making sure training programme reflects the objective of the individual. Higher ranked players were shown to have higher volumes (tennis and total) of training than lower-ranked players which agrees with previous literature. Therefore, those seeking to be internationally successful may require higher volumes of both tennis and physical training than regional players.
- Coaches should be mindful that female players appear to specialise earlier and/or play less sports than males, so may stop receiving sufficient athletic development stimuli from other sources at an earlier age. Therefore, increasing dependency on the athletic development provided in their tennis training programme.
- It could be recommended that when designing programme for elite players of this age, focus is placed on creating time for physical training or allowing a more integrated approach for those who are time poor.

Chapter 6: Training structure

- It should be considered that the inclusion of a supervised S&C programme with a performance tennis programme may result in superior physical development of players than a less structured format.
- The players with highest physical training volumes before the age of 12 had the most well-rounded athletic profiles implying the positive impact of S&C and supporting the introduction of training from an early age.

Data guiding Talent Identification processes for athlete funding or team selection

Chapter 4: Physical advantages of advanced maturation

- The influence of maturation should always be considered by coaches working with youth populations. There is increasing evidence of the relative age effect in junior tennis populations, but this trend is less evident at professional level when full maturity is reached.
- The physical and anthropometric advantages afforded by advanced maturity have been shown to benefit players, particularly in key areas dictating tennis performance (upper body strength and power, serve velocity). Therefore, being mindful that younger players performing close to or at a similar level in physical fitness tests to older players may have more scope for potential future physical development.
- Coaches should aim to avoid over selection of biologically older players within birth years, as how many players are lost from the sport as a result of being overlooked during adolescence for funding or competitive opportunities is unknown.

Chapter 5: Impact of training experience and volumes

- Consider the impact of the current training schedule and previous training experience of players, bearing in mind that those with greater training experience and higher physical training volumes are more likely to have a higher playing level and have more well-rounded athletic profiles. Conversely, also consider that players competing for funding or team spots whose training programme is not meeting recommended volumes for elite players may significantly improve with the right training support.

Chapter 6: Individual development trajectories

- The individual trajectory of athletic development is variable, and development of physical fitness qualities is not necessarily linear.
- By age 15 the superior physical performance seen in early maturer's at age 11 has mostly been lost indicating that on-time and later maturing athletes have "caught up"
- Mean longitudinal trends imply that physical performance of female players in speed, agility and power plateaus at age 14, whereas males follow an exponential improvement trend up until 15 years old.

The experimental chapters 7-9 produced novel findings in understanding the relationship between movement competency and performance, as well a method of assessment for monitoring the development of these fundamental movement skills. Secondly, the interventions investigated were the first to do so in this population (U14 and inclusive of females), therefore although further clarification will be required provide an initial indicator as to their effectiveness.

Evidence-based recommendations regarding the efficacy of the use of movement screens in junior tennis populations and practical applications of their findings

Chapter 7

- This thesis showed FMS competency can be linked to an athlete's ability to play tennis, therefore supporting the process of assessing this as part of understanding the exercise prescription requirements for junior tennis players.
- Consider the inclusion of assessment, monitoring and corrective exercise prescription for FMS as part of the physical development plan of junior tennis players. This should be done continuously throughout adolescence given the substantial amount of physical growth and physiological change that happens throughout this period (Malina et al., 2015, Lloyd et al., 2014, Lloyd and Oliver, 2012).
- Additionally, it should be considered that strongest relationships established between screening scores and physical variables were the same ones that presented the strongest relationship to tennis performance markers (agility, upper body strength and power). The only other study conducted after the data collection of this thesis, also found agility and acceleration to have significant correlation to FMS™ screening. (Yildiz, 2018). Subsequently, when attempting to improve performance in these variables FMS development should be strongly considered in the exercise prescription. As these interrelationships indicate that improvements in this area should lead to performance enhancement in physical fitness performance and potentially tennis performance.
- The AAA as a screening tool has similar ecological validity to other screenings as it can be done in a gym or on court with minimal equipment, with good inter-rater reliability, but lacks comparison to other movement screening tools in tennis.
- Consider prioritising FMS skills underlying hopping and lateral bounding (e.g., single leg strength and stability, dynamic balance), as these two components appear to have the strongest relationship to tennis performance. This may reflect the high change of direction and lateral movement demands present in the sport.

Evidence-based recommendations based on findings of S&C training interventions.

Chapter 8

- Consider the use of short 6-week protocols (2 sessions per week) as an effective method of improving FMS competency in post-PHV players. Pre-PHV players may require longer training blocks or greater frequency of sessions to make significant change.
- This is particularly relevant for those working with talented players that start S&C training post-PHV, as they may be behind other elite players in terms of physical development (Fett et al., 2017).

- Consider that FMS training prior to puberty can provide foundational blocks for athletic performance and may be a more effective method of enhancing these capabilities than directly working on the components of fitness individually (e.g., strength training, speed training etc).
- The variation in responses between maturity groups supports the requirement to prescribe training based on biological age rather than chronological age (Cobley et al., 2014, Lloyd et al., 2014).

Chapter 9

- A 6-week strength training programme is an effective way of improving FMS and fitness components of young tennis players aged 11-15 years old.
- Acute improvement in serve velocity may require serve specific programming and/or more time to see transfer to skill execution.

10.4 Future Research

Considering the findings and limitations of this thesis, the following key recommendations can be made for future research:

- More research following players longitudinal development of physical fitness characteristics from many current top players is required. As this could answer questions on the following:
    - How change in physical fitness characteristics changes tennis performance over time?
    - If the same characteristics correlating to performance during adolescence exist at professional level or if there is a plateau effect at a certain level?
- Future research focusing on longitudinally tracking training characteristics through adolescence to professional level would better inform training volume prescription across all ages.
    - Findings of Chapter 6 implied the superiority of well-structured, supervised training programme over more informal training pathways. In this case as a result of the provision of funding and coaching provision based on talent identification at age 11. Quantifying the impact of receiving these opportunities versus missing out on selection is often difficult (Cobley et al., 2014, Till et al., 2013), as the progress of those not selected is no longer monitored. By following a larger number of athletes and recording their training details, it may be possible to build a picture of what a successful training pathway looks like, rather than depending on guideline recommendations.

    - Additionally, looking even further ahead future studies can eventually look to use the detailed longitudinal training history data of professional players. This provides scope to use a retrospective approach to analyse the protective or detrimental effect of junior training characteristics, regarding factors such as injury frequency and severity, career success and longevity. This is not to say a one-size fits all approach will be administered as a result, but eventually it can create sufficient data to inform evidence-based practice.
- The relationship between movement competency and performance requires further substantiation via larger sample sizes and in different age groups. Currently whether this correlation has any predictive ability to use this assessment of potential ability is unknown, as we do not know if it exists at senior level or can be linked to other factors influencing professional success such as injury risk and severity or career longevity.
- The AAA was selected as screening tool for movement competency in this thesis, but only one study completed since has completed a similar investigation using a different protocol for comparison (Yildiz, 2018). Examining the efficacy of multiple protocols to establish which is the most valid or useful for this population.
- Methodological improvements in future intervention studies, such as the use of a control group, larger sample sizes, stricter participation criteria and control of tennis training volumes would improve accuracy of conclusions and wider application to larger populations.
- It was only possible to observe the acute effects of the interventions on performance and future research should focus on how training interventions to improve FMS or strength influence physical development or affect ranking over time.
- Findings of Chapters 8 and 9 form a starting point for first-hand data from the populations in this thesis but much is still to be determined. Intervention research is still very limited in number in this age group and there is huge scope for further research providing more information on different training types, frequencies and in specific populations (e.g., female only), amongst other factors.

In conclusion in completing this thesis, it was evident that there are several under researched areas when it comes to the application of strength and conditioning practices within junior tennis populations. It is hoped it has achieved its goal in starting to fill some of these gaps and gained deeper understanding into the role of S&C on the athletic development of junior players. This thesis has been one of the first to take a more detailed look at topics not previously been examined, specifically the influence of training characteristics (age started, volumes, type and structure) and FMS on performance. The latter of the two topics highlighting significant relationships between movement competency and tennis performance, indicating that assessment and coaching of these skills should be considered a key part of a junior tennis players athletic development. In addition, the two intervention studies demonstrating that simple 6-week interventions focused on FMS and strength development can improve both markers of movement competency and physical fitness performance. In turn, given the previously established relationships between these measures and tennis performance in Chapter 4 this should lead to an improved ability to play tennis, although will need further clarification in future research. Overall, this data has provided S&C coaches with much needed empirical data in this population to allow more objective evidence-based practice.

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Appendices

Appendix A – Ethics Approval for Chapters 4-9

AUTEC Secretariat

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

10 May 2016

Michael McGuigan
Faculty of Health and Environmental Sciences

Dear Michael

Re Ethics Application: **16/131 The effects of strength and conditioning on the physical performance of junior tennis players.**

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

Your ethics application has been approved for three years until 9 May 2019.

As part of the ethics approval process, you are required to submit the following to AUTEC:

- A brief annual progress report using form EA2, which is available online through http://www.aut.ac.nz/researchethics. When necessary this form may also be used to request an extension of the approval at least one month prior to its expiry on 9 May 2019;
- A brief report on the status of the project using form EA3, which is available online through http://www.aut.ac.nz/researchethics. This report is to be submitted either when the approval expires on 9 May 2019 or on completion of the project.

It is a condition of approval that AUTEC is notified of any adverse events or if the research does not commence. AUTEC approval needs to be sought for any alteration to the research, including any alteration of or addition to any documents that are provided to participants. You are responsible for ensuring that research undertaken under this approval occurs within the parameters outlined in the approved application.

AUTEC grants ethical approval only. If you require management approval from an institution or organisation for your research, then you will need to obtain this.

To enable us to provide you with efficient service, please use the application number and study title in all correspondence with us. If you have any enquiries about this application, or anything else, please do contact us at ethics@aut.ac.nz.

All the very best with your research,

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

Cc: Emily Fanning efanning@aut.ac.nz, Andrew Kilding

Appendix B – Advert Sheet Study 1 (Chapter 4)

SPORTS PERFORMANCE
RESEARCH INSTITUTE, NEW ZEALAND
AN INSTITUTE OF AUT UNIVERSITY

Are you a junior tennis player looking to improve your performance?

The Sports Performance Research Institute New Zealand is seeking junior tennis players to participate in a based study based at the National championships at Scarbro Tennis centre, Auckland. The study is designed to determine: (1) Existing physical traits of successful junior players in New Zealand (2) The relationship between physical fitness and tennis performance.

To be eligible to participate in this study you must:

- **Be between 10-14 years old.**
- **Currently play tennis twice a week or more and are competing the 2016/2017 National Championships**
- **Currently be free of any musculoskeletal injuries; acute or chronic, as well as having no psychological disorder, that may affect your physical or mental ability during the study**
- **Be able to provide informed written consent from your parent or legal guardian to participate in this study.**

This study will involve a one-off testing session measuring fitness, movement skills and tennis skills. This will take place 24-48hours before the start of the tournament. You will be asked to complete several short tests, such as sprinting, jumping, throwing and measures of flexibility, your total exercise volume will be no more than 30 minutes including a warm-up and cool down. At the conclusion of the study participants will have the opportunity to attend a presentation discussing the study findings, as well as receive an individualised report of testing results.

If you would like any further information regarding this study, or would like to express your interest in being a participant of this study please contact Emily, efanning@aut.ac.nz

Appendix C – Information Sheet Study 1 (Chapter 4)

SPORTS PERFORMANCE
RESEARCH INSTITUTE, NEW ZEALAND
AN INSTITUTE OF AUT UNIVERSITY

AUT
TE WĀNANGA ARONUI O TĀMAKI MAKAU RAU

Participant Information Sheet

April 11th, 2016

Project Title

The effects on strength and conditioning on the physical performance of junior tennis players

An Invitation

Hi, my name is Emily Fanning, I am a PhD student at Auckland University of Technology, I would like to invite you to participate in a research project looking at the effects of youth strength and conditioning on the physical performance of junior tennis players. Before you decide, please read the information below to find out more of what this project is all about. After which, you need to decide whether or not you would like to be involved.

Purpose of this research

The main purpose of the project is attempt to get more information about the athletic development of young tennis players. Although we know tennis requires good all-around fitness, we would like to know more about this and how this influences tennis performance. A key part of this research is to discover if starting fitness training at younger age makes you a better tennis player as you get older. Furthermore, the findings of this research will contribute towards a PhD qualification and may be used for publication in scientific journals.

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

You are a junior (<14yrs old) tennis player, Tennis is your main sport, and you compete regularly.

However, you will not be able to take part in this study if you identify with any of the following:

- You have an illness or injury that would limit your performance or put you at risk of further injury.
- You don't want height or weight measured for religious or cultural reasons
- You have any reason, medical or otherwise, to consider that you are not in good health

What will happen in this research?

Before participating in this research you will need to read through this information sheet and provide your informed approval to take part by returning the signed form. Your parent or legal guardian will need to read the "Parent of participant information sheet" and also sign the "Parent Consent Form" before you can do the study.

Feedback regarding your results will be given after all participants have completed the final measurements.

After you decide whether to participate in the research you will first attend a testing session on indoor court at the venue of your National Championships. This session will last between 2-3 hours and will only be completed once.

Testing:

- You will receive information and demonstrations of the tests you are about to participate and will have the opportunity to ask any questions you may have.
  All participants will then complete a standardized warm up lead by the primary researcher, after this testing will begin.
- *Physical fitness tests*: Firstly, your measurements will be taken including height, weight and sitting height. You will then complete the following tests:
- Speed – 20m sprint
- Change of direction- Forehand and Backhand agility= Starting in the middle you will sprint to one side touch the cone with your racquet hand, change direction and return to the middle as quickly as possible
- Power – Lower body - You will do two different jumping tests, a squat jump and a countermovement jump where you will try to jump as high as you can. Upper body you will two overhead throws as far as you can with a 1kg medicine ball.
- Strength – Grip strength will be used to assess your upper body strength and this will be done with a simple squeeze test.

Feedback regarding your results will be given after all participants have completed the final measurements.

What are the discomforts and risks?

Following testing sessions, you may experience mild muscle soreness as a participant in this study like that you may experience after a light training session. All tests and assessments are fully supervised, and a thorough warm-up performed before testing starts to reduce injury risk.

What are the benefits?

You will receive feedback which provides an overall picture of your fitness and highlights your strengths and your areas for improvement. The results of the testing can help to guide your coach (if you have granted permission for results to be shared) to change your training to help improve your overall performance.

What compensation is available for injury or negligence?

In the unlikely event of injury during the study, rehabilitation and compensation for injury by accident may be available from the Accident Compensation Corporation (ACC).

How will my privacy be protected?

All data collected in this study will be available only to the researchers involved. Your name will not be on any published work, and your data will remain anonymous and confidential after the study has finished and placed into a computer database where it could be accessed for future research projects in strength and conditioning. Any video footage taken in the testing will also be made so that you cannot be identified in any publication. We will make sure that any of your social and cultural requirements are respected and accommodated at their upmost.

What are the costs of participating in this research?

There are no costs to taking part in this research other than your time. Your time is all that is required if you choose to take part, this will be is 1-1.5 hours as you will be tested in a group, but you will likely only be completing a maximum of 15 minutes' total exercise during that time.

What opportunity do I have to consider this invitation?

Take your time to decide if you want to participate in the study, and give us your decision in four weeks' time from the moment you read this Information Sheet. Please note that participation in this study is voluntary and you have the right to stop taking part at any point until the testing is finished, for any reason, without a problem.

Will I receive feedback on the results of this research?

After the project is finished you will be provided with feedback of your results, you can also receive more information or advice from me in person if you want. Your results will only be shared with your coach if you have granted us permission to do so.

How do I join the study?

If you are interested in taking part in this study the next step is to contact me (Emily, contact details below), I can then answer any further questions you may have, provide you with a consent form, and further details regarding the data collection process. Once you have signed and returned the consent form you may participate in the study, provided you meet the criteria listed above.

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

Any concerns regarding the this project should be notified in the first instance to the Project Supervisor: Professor Michael McGuigan, michael.mcguigan@aut.ac.nz, +64921 9999 ext 7580

Concerns regarding the conduct of the research should be notified to the Executive Secretary, AUTEC, Kate O'Connor, *ethics@aut.ac.nz*, 09 921 9999 ext 6038.

Whom do I contact for further information about this research?

Researcher Contact Details:
Name: Emily Fanning
E-mail: efanning@aut.ac.nz
Phone: +64 2040483044

Appendix D – Consent and Assent Form Study 1 (Chapter 4)

page 1 of 1

Consent Form	AUT UNIVERSITY TE WĀNANGA ARONUI O TAMAKI MAKAU RAU

Project title: **Physical traits and trends amongst NZ junior tennis players and their relationship to performance**

Primary Researcher: **Emily Fanning, PhD student**

(Please Tick)

- O I have read and understood the information provided about this research project in the Information Sheet.
- O I have had an opportunity to ask questions and to have them answered.
- O I am not suffering from heart disease, high blood pressure, any respiratory condition (mild asthma excluded), any illness or injury that impairs my physical performance.
- O I understand that I may withdraw myself or any information that I have provided for this project at any time prior to completion of data collection, without being disadvantaged in any way.
- O I understand there may be some mild discomfort associated with measures in this research, but this will not be beyond that of my normal training level.
- O I am not suffering from any illness or injury that may prevent me from being able to complete the tasks detailed in the information sheet.
- O I am happy for my coach to see my test data.
- O I agree to my de-identified performance data being kept indefinitely in storage for future analysis/research purposes, and my personal details being stored in a locked cabinet for a period of six years before being destroyed.
- O I agree to take part in this research.
- O I wish to receive a copy of the report from the research (please tick one): Yes O No O

Participant signature : ....

Participant Name : ....

Participant contact Details :..

Date:..

Parent/Legal Guardian signature : ....

Parent/Legal Guardian Name :..

Parent/Legal Guardian contact details (if different from participant) ....

....

Date :..

Approved by the Auckland University of Technology Ethics Committee on 10th May 2016.

***AUTEC Reference number* 16/131/**

Appendix E – Chapter 4: Spearman's Correlations between physical fitness, growth and anthropometric characteristics

	U12 Females	Age	Height	Sitting Height	Weight	APHV	Biological Age	Grip Strength	Grip Strength	CMJ	SJ	Overhead Medicine	Forehand Agility	Backhand Agility	5m	10m	20m
U12 Girls	**Age**	1.00	**0.55**	**0.44**	**0.52**	0.33	**0.84**	**0.49**	**0.47**	0.29	0.19	**0.41**	-0.09	-0.12	-0.01	-0.11	-0.21
	Height	**0.55**	1.00	**0.81**	**0.77**	**-0.53**	**0.86**	**0.80**	**0.89**	0.10	0.11	**0.61**	-0.05	-0.08	-0.09	-0.16	-0.20
	Sitting Height	**0.44**	**0.81**	1.00	**0.64**	**-0.51**	**0.75**	**0.79**	**0.81**	-0.01	0.10	**0.60**	0.01	-0.17	-0.18	-0.22	-0.23
	Weight	**0.52**	**0.77**	**0.64**	1.00	**-0.43**	**0.82**	**0.70**	**0.80**	-0.09	-0.20	**0.59**	0.24	0.26	0.28	0.24	0.13
	APHV	0.33	**-0.53**	**-0.51**	**-0.43**	1.00	-0.20	**-0.39**	**-0.52**	0.22	0.21	-0.34	-0.06	-0.01	0.02	-0.04	-0.03
	Biological Age	**0.84**	**0.86**	**0.75**	**0.82**	-0.20	1.00	**0.77**	**0.82**	0.13	0.03	**0.65**	-0.01	-0.04	0.02	-0.06	-0.17
	Grip Strength Dominant	**0.49**	**0.80**	**0.79**	**0.70**	**-0.39**	**0.77**	1.00	**0.90**	0.14	0.20	**0.73**	-0.19	-0.08	-0.07	-0.18	-0.28
	Grip Strength Non-Dom	**0.47**	**0.89**	**0.81**	**0.80**	**-0.52**	**0.82**	**0.90**	1.00	0.05	0.04	**0.71**	-0.05	-0.01	0.01	-0.06	-0.14
	CMJ	0.29	0.10	-0.01	-0.09	0.22	0.13	0.14	0.05	1.00	**0.66**	0.14	**-0.45**	-0.37	**-0.44**	**-0.51**	**-0.53**
	SJ	0.19	0.11	0.10	-0.20	0.21	0.03	0.20	0.04	**0.66**	1.00	0.14	**-0.66**	**-0.57**	**-0.55**	**-0.64**	**-0.57**
	Overhead Medicine Ball	**0.41**	**0.61**	**0.60**	**0.59**	-0.34	**0.65**	**0.73**	**0.71**	0.14	0.14	1.00	-0.34	-0.29	-0.21	-0.30	**-0.48**
	Forehand Agility	-0.09	-0.05	0.01	0.24	-0.06	-0.01	-0.19	-0.05	**-0.45**	**-0.66**	-0.34	1.00	**0.77**	**0.61**	**0.72**	**0.78**
	Backhand Agility	-0.12	-0.08	-0.17	0.26	-0.01	-0.04	-0.08	-0.01	-0.37	**-0.57**	-0.29	**0.77**	1.00	**0.66**	**0.73**	**0.77**
	5m	-0.01	-0.09	-0.18	0.28	0.02	0.02	-0.07	0.01	**-0.45**	**-0.55**	-0.21	**0.61**	**0.66**	1.00	**0.95**	**0.83**
	10m	-0.11	-0.16	-0.22	0.24	-0.04	-0.06	-0.18	-0.06	**-0.51**	**-0.64**	-0.30	**0.72**	**0.73**	**0.95**	1.00	**0.92**
	20m	-0.21	-0.20	-0.23	0.13	-0.03	-0.17	-0.28	-0.14	**-0.53**	**-0.57**	**-0.48**	**0.78**	**0.77**	**0.83**	**0.92**	1.00

	U12 Males	Age	Height	Sitting Height	Weight	APHV	Biological Age	Grip Strength	Grip Strength	Sit and Reach	CMJ	SJ	Overhead Medicine	Forehand Agility	Backhand Agility	5m	10m	20m
	Age	1.00	**0.59**	**0.44**	**0.42**	**0.68**	**0.80**	**0.44**	**0.61**	0.07	0.09	0.08	0.42	-0.15	-0.15	0.07	-0.04	-0.10
	Height	**0.59**	1.00	**0.81**	**0.58**	0.01	**0.84**	**0.59**	**0.59**	-0.04	**0.40**	**0.44**	**0.49**	-0.20	-0.34	-0.19	-0.34	**-0.36**
	Sitting Height	**0.44**	**0.81**	1.00	**0.68**	-0.28	**0.79**	**0.59**	**0.60**	0.16	**0.37**	**0.38**	**0.40**	-0.21	**-0.43**	-0.23	-0.33	-0.32
	Weight	**0.42**	**0.58**	**0.68**	1.00	-0.23	**0.76**	**0.68**	**0.60**	0.03	0.04	0.15	**0.39**	0.02	-0.21	-0.10	-0.10	-0.09
	APHV	**0.68**	0.01	-0.28	-0.23	1.00	0.19	-0.11	0.11	0.00	-0.07	-0.11	0.09	-0.14	0.10	0.17	0.11	0.03
	Biological Age	**0.80**	**0.84**	**0.79**	0.76	0.19	1.00	**0.63**	**0.72**	0.02	0.20	0.25	**0.51**	-0.11	-0.22	-0.01	-0.12	-0.16
U12	**Grip Strength Dominant**	**0.44**	**0.59**	**0.59**	**0.68**	-0.11	**0.63**	1.00	**0.87**	0.38	0.28	0.25	**0.76**	-0.14	-0.34	-0.21	-0.24	-0.23
	Grip Strength Non-Dominant	**0.61**	**0.59**	**0.60**	**0.60**	0.11	**0.72**	**0.87**	1.00	**0.40**	**0.37**	**0.35**	**0.75**	-0.24	**-0.40**	-0.21	-0.27	-0.29
	Sit and Reach	0.07	-0.04	0.16	0.03	0.00	0.02	0.38	**0.40**	1.00	0.16	0.09	**0.49**	-0.22	-0.29	-0.11	-0.12	-0.07
	CMJ	0.09	**0.40**	**0.37**	0.04	-0.07	0.20	0.28	**0.37**	0.16	1.00	**0.90**	**0.41**	**-0.60**	**-0.55**	**-0.76**	**-0.81**	**-0.81**
	SJ	0.08	**0.44**	**0.38**	0.15	-0.11	0.25	0.25	**0.35**	0.09	**0.90**	1.00	0.34	**-0.45**	**-0.47**	**-0.66**	**-0.74**	**-0.74**
	Overhead Medicine Ball Throw	**0.42**	**0.49**	**0.40**	**0.39**	0.09	**0.51**	**0.76**	**0.75**	**0.49**	**0.41**	0.34	1.00	-0.25	-0.21	-0.18	-0.23	-0.24
	Forehand Agility	-0.15	-0.20	-0.21	0.02	-0.14	-0.11	-0.14	-0.24	-0.22	**-0.60**	**-0.45**	-0.25	1.00	**0.70**	**0.74**	**0.81**	**0.79**
	Backhand Agility	-0.15	-0.34	**-0.43**	-0.21	0.10	-0.22	-0.34	**-0.40**	-0.29	**-0.55**	**-0.47**	-0.21	**0.70**	1.00	**0.70**	**0.72**	**0.66**
	5m	0.07	-0.19	-0.23	-0.10	0.17	-0.01	-0.21	-0.21	-0.11	**-0.76**	**-0.66**	-0.18	**0.74**	**0.70**	1.00	**0.92**	**0.87**
	10m	-0.04	-0.34	-0.33	-0.10	0.11	-0.12	-0.24	-0.27	-0.12	**-0.81**	**-0.74**	-0.23	**0.81**	**0.72**	**0.92**	1.00	**0.98**
	20m	-0.10	**-0.36**	-0.32	-0.09	0.03	-0.16	-0.23	-0.29	-0.07	**-0.81**	**-0.74**	-0.24	**0.79**	**0.66**	**0.87**	**0.98**	1.00

	U14 Females	**Age**	**Height**	**Sitting Height**	**Weight**	**APHV**	**Biological Age**	**Grip Strength**	**Grip Strength**	**Sit and Reach**	**CMJ**	**SJ**	**Overhead Medicine**	**Forehand Agility**	**Backhand Agility**	**5m**	**10m**	**20m**
U14	**Age**	1.00	-0.11	-0.11	-0.05	**0.55**	**0.57**	-0.16	0.09	-0.14	**0.49**	0.29	-0.04	-0.19	-0.05	0.02	-0.08	-0.23
	Height	-0.11	1.00	0.80	**0.72**	**-0.79**	**0.62**	**0.47**	0.37	-0.17	-0.33	-0.16	**0.50**	-0.32	-0.26	-0.42	-0.33	-0.24
	Sitting Height	-0.11	**0.80**	1.00	**0.69**	**-0.80**	**0.62**	**0.52**	**0.56**	-0.18	-0.13	-0.02	**0.59**	**-0.60**	-0.36	-0.42	-0.36	-0.40
	Weight	-0.05	**0.72**	**0.69**	1.00	**-0.68**	**0.62**	**0.60**	**0.49**	-0.02	-0.21	-0.01	**0.52**	-0.35	**-0.55**	**-0.66**	**-0.53**	**-0.52**
	APHV	**0.55**	**-0.79**	**-0.80**	**-0.68**	1.00	-0.23	**-0.56**	-0.38	0.23	**0.42**	0.27	**-0.53**	0.28	0.18	**0.44**	0.30	0.22
	Biological Age	**0.57**	**0.62**	**0.62**	**0.62**	-0.23	1.00	0.33	**0.49**	-0.14	0.16	0.21	0.28	**-0.48**	-0.37	**-0.44**	-0.40	**-0.48**
	Grip Strength Dominant	-0.16	**0.47**	**0.52**	**0.60**	**-0.56**	0.33	1.00	**0.88**	0.36	0.09	0.25	0.32	**-0.52**	**-0.46**	**-0.46**	**-0.51**	**-0.50**
	Grip Strength Non-Dominant	0.09	0.37	**0.56**	**0.49**	-0.38	**0.49**	**0.88**	1.00	0.41	0.30	**0.49**	0.31	**-0.75**	**-0.45**	**-0.47**	**-0.57**	**-0.67**
	Sit and Reach	-0.14	-0.17	-0.18	-0.02	0.23	-0.14	0.36	0.41	1.00	0.10	**0.68**	0.27	-0.48	**-0.67**	-0.19	-0.44	-0.50
	CMJ	**0.49**	-0.33	-0.13	-0.21	**0.42**	0.16	0.09	0.30	0.10	1.00	**0.63**	-0.41	-0.28	-0.12	-0.05	-0.30	-0.32
	SJ	0.29	-0.16	-0.02	-0.01	0.27	0.21	0.25	**0.49**	**0.68**	**0.63**	1.00	-0.20	**-0.54**	-0.37	-0.24	**-0.50**	**-0.50**
	Overhead Medicine Ball Throw	-0.04	**0.50**	**0.59**	**0.52**	**-0.53**	0.28	0.32	0.31	0.27	-0.41	-0.20	1.00	**-0.49**	**-0.52**	-0.26	-0.26	-0.29
	Forehand Agility	-0.19	-0.32	**-0.60**	-0.35	0.28	**-0.48**	**-0.52**	**-0.75**	-0.48	-0.28	**-0.54**	**-0.49**	1.00	**0.63**	0.30	**0.53**	**0.62**
	Backhand Agility	-0.05	-0.26	-0.36	**-0.55**	0.18	-0.37	**-0.46**	**-0.45**	**-0.67**	-0.12	-0.37	**-0.52**	**0.63**	1.00	**0.55**	**0.71**	**0.72**
	5m	0.02	-0.42	-0.42	**-0.66**	**0.44**	**-0.44**	**-0.46**	**-0.47**	-0.19	-0.05	-0.24	-0.26	0.30	**0.55**	1.00	**0.88**	**0.84**
	10m	-0.08	-0.33	-0.36	**-0.53**	0.30	-0.40	**-0.51**	**-0.57**	-0.44	-0.30	**-0.50**	-0.26	**0.53**	**0.71**	**0.89**	1.00	**0.92**
	20m	-0.23	-0.24	-0.40	**-0.52**	0.22	**-0.48**	**-0.50**	**-0.67**	-0.50	-0.32	**-0.50**	-0.29	**0.62**	**0.72**	**0.84**	**0.92**	1.00

	U14 Males	Age	Height	Sitting Height	Weight	APHV	Biological Age	Grip Strength	Grip Strength	Sit and Reach	CMJ	SJ	Overhead Medicine	Forehand Agility	Backhand Agility	5m	10m	20m
U14	**Age**	1.00	**0.44**	0.35	**0.51**	-0.06	**0.65**	**0.54**	**0.46**	-0.11	-0.05	0.14	**0.52**	-0.08	-0.27	-0.09	-0.10	-0.34
	Height	**0.44**	1.00	**0.93**	**0.95**	**-0.84**	**0.88**	**0.72**	**0.63**	0.05	0.13	0.10	**0.54**	-0.15	-0.30	0.00	-0.03	-0.29
	Sitting Height	0.35	**0.93**	1.00	**0.93**	**-0.94**	**0.90**	**0.60**	**0.52**	-0.10	-0.06	0.07	0.35	-0.28	-0.21	-0.26	-0.19	-0.40
	Weight	**0.51**	**0.95**	**0.93**	1.00	**-0.84**	**0.91**	**0.73**	**0.58**	0.08	0.06	0.09	**0.46**	-0.04	-0.31	0.02	-0.02	-0.30
	APHV	-0.06	**-0.84**	**-0.94**	**-0.84**	1.00	**-0.74**	**-0.48**	-0.40	0.09	0.00	-0.03	-0.14	0.23	0.14	0.22	0.17	0.33
	Biological Age	**0.65**	**0.88**	**0.90**	**0.91**	**-0.74**	1.00	**0.70**	**0.62**	-0.12	-0.09	-0.02	**0.60**	-0.29	-0.36	-0.30	-0.23	**-0.49**
	Grip Strength Dominant	**0.54**	**0.72**	**0.60**	**0.73**	**-0.48**	**0.70**	1.00	**0.91**	0.02	0.12	-0.02	**0.57**	-0.25	-0.31	-0.06	-0.18	-0.33
	Grip Strength Non-Dominant	**0.46**	**0.63**	**0.52**	**0.58**	-0.40	**0.62**	**0.91**	1.00	0.02	0.25	0.05	**0.57**	-0.38	-0.28	-0.22	-0.32	**-0.41**
	Sit and Reach	-0.11	0.05	-0.10	0.08	0.09	-0.12	0.02	0.02	1.00	0.21	-0.01	0.08	0.18	-0.28	0.22	0.05	0.03
	CMJ	-0.05	0.13	-0.06	0.06	0.00	-0.09	0.12	0.25	0.21	1.00	**0.45**	0.01	-0.19	-0.34	-0.24	**-0.45**	**-0.45**
	SJ	0.14	0.10	0.07	0.09	-0.03	-0.02	-0.02	0.05	-0.01	**0.45**	1.00	-0.13	-0.20	-0.27	**-0.42**	**-0.46**	**-0.46**
	Overhead Medicine Ball Throw	**0.52**	**0.54**	0.35	**0.46**	-0.14	**0.60**	**0.57**	**0.57**	0.08	0.01	-0.13	1.00	-0.23	**-0.52**	-0.03	-0.03	-0.22
	Forehand Agility	-0.08	-0.15	-0.28	-0.04	0.23	-0.29	-0.25	-0.38	0.18	-0.19	-0.20	-0.23	1.00	**0.41**	**0.62**	**0.65**	**0.56**
	Backhand Agility	-0.27	-0.30	-0.21	-0.31	0.14	-0.36	-0.31	-0.28	-0.28	-0.34	-0.27	**-0.52**	**0.41**	1.00	0.31	**0.47**	**0.60**
	5m	-0.09	0.00	-0.26	0.02	0.22	-0.30	-0.06	-0.22	0.22	-0.24	**-0.42**	-0.03	**0.62**	0.31	1.00	**0.88**	**0.80**
	10m	-0.10	-0.03	-0.19	-0.02	0.17	-0.23	-0.18	-0.32	0.05	**-0.45**	**-0.46**	-0.03	**0.65**	**0.47**	**0.88**	1.00	**0.87**
	20m	-0.34	-0.29	-0.40	-0.30	0.33	**-0.49**	-0.33	**-0.41**	0.03	**-0.45**	**-0.46**	-0.22	**0.56**	**0.60**	**0.80**	**0.87**	1.00

Appendix F – Chapter 5: Participant Questionnaire

Participant Questionnaire

1. Name

   ____

2. Date of birth

   ____

3. Left or Right Handed

   Mark only one oval.

   ◯ Left
   ◯ Right

4. Current Grading

   Mark only one oval.

   ◯ S1
   ◯ S2
   ◯ S3
   ◯ S4
   ◯ S5
   ◯ S6
   ◯ S7
   ◯ S8

5. Current National Age Group Ranking

   ____

6. Age you started tennis

____

7. Current tennis training hours per week

____

8. If you can remember, please write the average Tennis Training hours per week in previous years (please attempt to fill in a minimum of two years prior to this year)

____
____
____
____
____

9. How many tournaments do you play per year

Mark only one oval.

- ◯ 0-5
- ◯ 5-10
- ◯ 10-15
- ◯ 15-20
- ◯ 20-25
- ◯ 25+

10. Do you participate in fitness training ?

Mark only one oval.

- ◯ Yes
- ◯ No
- ◯ Sometimes

11. If yes, who takes your training?

Mark only one oval.

- ◯ Fitness coach at Tennis
- ◯ Fitness coach
- ◯ Tennis coach
- ◯ Parent
- ◯ I do it myself

12. How many hours of fitness training do you do per week?

____

13. What age did you start doing fitness training

Mark only one oval.

- ◯ Age 7
- ◯ Age 8
- ◯ Age 9
- ◯ Age 10
- ◯ Age 11
- ◯ Age 12
- ◯ Age 13
- ◯ Age 14
- ◯ Age 15
- ◯ Age 16

14. Can you recall how many hours of fitness training you did on average per in week in previous years?

15. Do you play other sports?

Mark only one oval.

- Yes
- No
- Sometimes

16. If yes, what sport(s)

17. If yes, how many hours of other sports do you play per week?

Mark only one oval.

- 0-2hours
- 2-4hours
- 4-6hours
- 6-8hours
- 8hours +

18. If you do NOT play other sports now and did before what age did you stop ?

19. Have you had any injuries, that kept you out of sport for any of the given time periods below?

Mark only one oval.

- 2 days
- 1 week
- 2 weeks
- 3 weeks
- 1 month
- 3 months
- 6 months
- 1 year +
- I have never had an injury which has stopped me from training

20. How many injuries have you required medical treatment for (physiotherapy, chiropractor, doctor etc)

Mark only one oval.

- 1-3
- 4-6
- 7-10
- 10+

– Chapter 5: Injury frequency and severity data

Appendix G – Chapter 5: Injury frequency and Severity

Age Started Fitness	7	0%	0%	0%	4.0%
	8	3.4%	8	3.4%	0%
	9	13.8%	9.4%	0%	0%
	10	31.0%	31.3%	4.2%	20%
	11	27.6%	18.8%	4.2%	8.0%
	12	3.4%	3.1%	33.3%	44%
	13	n/a	n/a	20.8%	12.0%
	14	n/a	n/a	12.5%	4.0%
	DNR	20.7%	28.1%	25%	8%

Appendix H – Chapter 6: Longitudinal training history questionnaire

Training History Questionnaire Age 12-15

1. Name

____

TRAINING HISTORY AGE 12

2. How many hours per week of tennis training did you do age 12 ?

   Mark only one oval.

   - 0-2
   - 2-4
   - 4-6
   - 6-8
   - 8-10
   - 10-12
   - 12+

3. How many hours of fitness training hours per week age 12?

   Mark only one oval.

   - None
   - 1-2hours
   - 2-3hours
   - 3-4hours
   - 5-6hours
   - 6+

4. If you did any fitness age 12 - where did you do it ?

Mark only one oval.

- ◯ I didn't do any
- ◯ At home
- ◯ At gym
- ◯ At school

5. Who did you do the majority of your fitness training with age 12 ?

Mark only one oval.

- ◯ I didn't do any
- ◯ On my own
- ◯ With parent
- ◯ In private session with tennis coach
- ◯ In group session with fitness coach
- ◯ In private session with fitness/S&C coach
- ◯ In group session with fitness/S&C coach

6. Did you follow a program from an S&C coach?

Mark only one oval.

- ◯ Yes
- ◯ No

7. Did you continue to play other sports on a regular basis?

Mark only one oval.

- ◯ Yes
- ◯ No

8. How many hours of other sports did you play per week?

____

TRAINING HISTORY AGE 13

9. How many hours per week of tennis training did you do age 13?

Mark only one oval.

- 0-2
- 2-4
- 4-6
- 6-8
- 8-10
- 10-12
- 12+

10. How many hours of fitness training did you do per week age 13?

Mark only one oval.

- None
- 1-2hours
- 2-3hours
- 3-4hours
- 5-6hours
- 6+

11. If you did any fitness age 13 - where did you do it ?

Mark only one oval.

- [ ] I didn't do any
- [ ] At home
- [ ] At gym
- [ ] At school

12. Who did you do the majority of your fitness training with age 13?

Mark only one oval.

- [ ] I didn't do any
- [ ] On my own
- [ ] With parent
- [ ] In private session with tennis coach
- [ ] In group session with tennis coach
- [ ] In private session with fitness/S&C coach
- [ ] In group session with fitness/S&C coach

13. Did you follow a program from an S&C coach?

Mark only one oval.

- [ ] Yes
- [ ] No

14. Did you play any other sports on a regular basis?

Mark only one oval.

- [ ] Yes
- [ ] No

15. How many hours tennis training did you do age 14?

Mark only one oval.

- 0-2
- 2-4
- 4-6
- 6-8
- 8-10
- 10-12
- 12-14
- 14+

16. How many hours of fitness per week did you do age 14?

Mark only one oval.

- I didn't do any
- 0-1 hour
- 1-2hours
- 2-3hours
- 3-4hours
- 5-6hours
- 6+hours

17. If you did any fitness age 14 - Where did you do it?

Mark only one oval.

- I didnt do any
- At home
- At the gym
- At school

18. Who did you do the majority of your fitness training with age 14?

Mark only one oval.

- ◯ I didn't do any
- ◯ On my own
- ◯ With parent
- ◯ In private session with tennis coach
- ◯ In group session with tennis coach
- ◯ In private session with fitness/S&C coach
- ◯ In group session with fitness/S&C coach

19. Did you follow a program from an S&C coach?

Mark only one oval.

- ◯ Yes
- ◯ No

20. Did you play any other sports on a regular basis?

Mark only one oval.

- ◯ Yes
- ◯ No

21. How many hours of other sport did you play?

____

TRAINING HISTORY AGE 15

22. How many hours per week of tennis training did you do age 15?

Mark only one oval.

- 0-2
- 2-4
- 4-6
- 6-8
- 8-10
- 10-12
- 12+

23. How many hours of fitness training hours per week age 15?

Mark only one oval.

- None
- 1-2hours
- 2-3hours
- 3-4hours
- 5-6hours
- 6+

24. If you did any fitness age 15 - where did you do it ?

Mark only one oval.

- I didn't do any
- At home
- At gym
- At school