The effects of strength and plyometric training on sprinting kinetics in young female athletes

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Abstract

Sprinting speed is a fundamental motor skill in many sports. The ability to move over short distances can significantly impact the outcome of a game. The natural development of sprinting is similar in boys and girls during the first decade of life. However, due to changes in hormonal levels during puberty the development of kinetic and kinematic variables associated with sprinting may be affected in young females compared to their male counterparts. It is believed that progressive strength and plyometric training can positively influence sprinting performance in youth. Previously researchers have investigated sprinting kinetics, kinematics and the effects of strength and plyometric training on sprinting performance in young males. However, there is a paucity of research in young females. Therefore, the purpose of this thesis was to investigate the kinetics and kinematics of sprinting speed in mid and post peak height velocity (PHV) females and further investigate the effects of strength and plyometric training on sprinting speed in post PHV female athletes.

Chapter 1 serves to provide the background, purpose, originality and the structure of the thesis. Chapter 2 reviewed natural development of sprinting speed in the youth population and informed that there is a paucity of research investigating sprinting kinetics and kinematics across maturation in young females. Chapter 3 reviewed existing research on the effects of strength (ST) and plyometric training (PT) on sprinting speed in the youth population, particularly young females. This chapter reported that there is limited research investigating the effects of ST and PT on sprinting speed in young females and no study to date has compared ST vs. PT on sprinting speed in young females**.** Chapter 4 measured the intraday (n=29) and inter-day reliability (n=14) of sprinting kinetics in young females using a radar gun since no previous reliability study has been conducted in this population. Sprinting kinetic variables including Force (*Fo*)*,* theoretical velocity (*Vo*)*,* maximal velocity (*Vmax*)*,* maximal power (*Pmax*)*,* 10, 20, 30 m split times using the radar gun showed acceptable reliability with intraclass correlation coefficient (ICC) ranging 0.74-0.98 and coefficient of variation (CV) ranging from 1.70-12.70% for both intra and inter-day analysis. Chapter 5 investigated the kinetics and kinematics of sprinting speed in mid (n=11) and post (n=21) PHV female athletes and reported that *Fo, Vo, Vmax, Pmax* and step length were significantly higher in post PHV girls than mid PHV girls ($p<0.05$).

In addition, univariate regression analysis reported that the predictors of *Vmax* over 15 m were contact time, *Pmax,* step frequency, and step length. Whereas the predictors of velocity over 30 m were contact time, leg length and *Pmax*, with contact time being the strongest predictor for both 15 and 30 m.

Chapter 6 investigated the effects of ST vs. PT on sprinting speed in post PHV female athletes (ST: n=16, PT: n=21, CON: n=15). It is reported that both the ST and PT groups significantly improved all performance variables ($p<0.05$). The ST significantly improved 10 m split time (6.76%; Cohen's *d*=0.66, Hedge's *g*=0.65) and *Fo* (16.36%; *d*=0.67, *g*=0.65) whereas the PT group significantly improved *Vmax* (4.91%; *d*=0.51, *g*=0.50), *Fo* (11.12%; *d*=0.40, *g*=0.40) and *Pmax* (7.88%; *d*=0.26, *g*=0.26). Post hoc analysis showed that both ST and PT groups had significantly higher post scores for *Vmax*, 30, 20,10 m split times and single-leg horizontal jumps (both sides) compared to the Control (CON) ($p<0.05$). There were no significant differences in post scores for any variable between the intervention groups. Chapter 7 investigated the effects of horizontal (HT) and vertical plyometric training (VT) on sprinting speed in post PHV female athletes (HT: n=10, VT: n=11, CON: n=9) and reported that following VT, participants showed significant improvements in *Vo, Vmax,* 10, 20 and 30 m sprint time with effect size (ES) ranging from (*d*=0.42, *g*=0.40 to *d*= 0.52, *g*= 0.50; $p<0.05$) but not *Fo* and *Pmax* whereas following HT, participants significantly improved all sprinting variables with greater effects (*d*= 0.49, *g*=0.47 to *d*=1.36, *g*=1.30; $p<0.05$) than the VT group. Post hoc analysis showed that the VT group had significantly higher post scores compared to the CON group for *Vo, Vmax*, vertical jump (VJ), and broad jump (BJ) whereas the HT group had significantly higher post scores for 20 m split time and BJ compared to the CON group ($p<0.05$). There were no significant differences in post scores for any variable between the intervention groups. Chapter 8 provided an overall summary which suggested that ST, HT and VT are effective means of improving sprinting kinetics in post PHV female athletes. Finally, chapter 9 provided practical suggestions in designing ST and PT programmes to develop sprinting speed in young females based on the findings of this thesis (chapter 6 and 7), and the two narrative reviews (chapters 2 and 3) respectively.

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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 institutions of higher learning.

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Kaushik Talukdar
12 October 2020

Co-Authored Works

Chapter 2 Talukdar, K., Harrison, C., McGuigan, M. Natural development of sprint speed in youth: a narrative review. *Strength and Conditioning Journal* In preparation.	Talukdar 80%, Harrison 15%, McGuigan 5%
Chapter 3 and Chapter 9 Talukdar, K., Harrison, C., McGuigan, M. Practical strategies in developing strength and plyometric training to improve sprinting speed in young female athletes. *Strength and Conditioning Journal* Submitted.	Talukdar 80%, Harrison 15%, McGuigan 5%
Chapter 4 Talukdar, K., Harrison, C., McGuigan, M. The intraday and inter-day reliability of sprinting kinetics in young female athletes measured using a radar gun. *Measurement in Physical Education and Exercise Science* Accepted.	Talukdar 80%, Harrison 10%, McGuigan 10%
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Chapter 7 Talukdar, K., Harrison, C., McGuigan, M., Borotkanics, R. The effects of horizontal and vertical plyometric training on	Talukdar 80%, Harrison 10%, McGuigan 5%,

sprinting kinetics in peak height velocity females. *Women in Sport and Physical Activity Journal* Submitted.	Borotkanics 5%

Kaushik Talukdar

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Ethics Approval

Ethical approval for this thesis research was granted by the Auckland University of Technology Ethics Committee (AUTEC) on 7th March 2019 for a period of three years.

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Chapter 1: Introduction

Background

Sprinting is considered a fundamental motor skill required to be successful in sports (Coyler, Nagahara, Takai, & Salo, 2020). In many sports, an athlete's ability to accelerate rapidly from static positions is key to successful performance (Cronin & Hansen, 2005). Crucially, sprinting speed is also an important factor in talent identification of youth athletes (Gil, Ruiz, Irazusta, Gil, Irajusta, 2007). Indeed, speed has been shown to distinguish elite and non-elite players in soccer (Murtagh et al., 2018) and field hockey (Keogh, Weber, & Dalton, 2003). However, sprinting performance tends to change across maturation in boys and girls (Rumpf et al., 2015; Nagahara et al., 2019). Therefore, understanding the factors that influence sprinting in the youth population can be crucial in overall athletic development.

It has been suggested that movement skills associated with sprinting can be achieved with tailored physical development programmes and modification of social and physical environment (Van Beurden et al., 2002). The need for tailored physical development programmes along with reinforcement of coordination patterns may be particularly important throughout adolescence when body dimensions are rapidly changing (Oliver, Lloyd & Rumpf, 2013). Furthermore, the ability to rapidly increase velocity (acceleration) is a key determinant to successful performance in many sports (Cronin & Hansen, 2005). This is one of the reasons why assessment of speed over a short distance ≤ 40 m is part of talent identification in various sports (Murtagh et al., 2018; Keogh et al., 2003). Previous studies have reported that elite male and female athletes are significantly faster over 10, 20 and 40 m distances than their non-elite counterparts ($p<0.01$ and $p<0.05$ respectively) (Murtagh et al., 2018; Keogh, Weber, & Dalton, 2003). More specifically, elite male soccer players demonstrated significantly faster 10 and 20 m sprint times compared to their non-elite counterparts across maturation (pre to post peak height velocity: PHV) ($p<0.001$) (Murtagh et al., 2018). However, sprinting performance tends to change with growth and maturation between genders during the second decade of life (Viru et al., 1999; Rumpf et al., 2015; Nagahara et al., 2019). Therefore, understanding the kinetics and kinematics associated with sprinting along with factors that influence sprinting performance during adolescence between genders is important.

Growth, maturation and gender differences associated with sprinting in youth

Sprint performance changes with growth and maturation (Rumpf et al., 2015; Meyers et al., 2015). Longitudinal studies report that sprinting speed in children improves linearly up until the age of approximately 5 years (Viru et al., 1999). Between the ages of 5 and 9 years, an increase in neural drive and coordination in both sexes results in a period of accelerated speed development (Borms,1986; Viru et al.,1999). For instance, Coyler et al. (2020) reported an accelerated development in sprinting around 4.5-5 years before PHV in boys and 1.5-2 years before PHV in girls. However, the natural development of sprint speed from the onset of puberty is different in boys and girls (Viru et al.,1999). Relative to body weight, while boys get stronger and faster, females get weaker and slower with increasing age (Whithall, 2003).

The reasons for this difference are not yet fully understood, but they may in part be due to circulating sex hormones. Specifically, increasing levels of oestrogens in girls, resulting in marked changes in body composition (Malina, Bouchard, & Bar-Or, 2004), likely affect the kinetics and kinematics of sprinting (Beunen & Malina,1988; Butterfield, Lehnhard, Lee, & Coladarci, 2004; Malina et al., 2004). For instance, research has shown an increase in propulsive forces (0.024 Ns/y) and step length (0.08m/y) in the younger Japanese girls ($<$12.7 years) compared to propulsive forces (-0.010 Ns/y) and step length (0.01m/y) in the older girls ($>$12.7 years) (Nagahara et al., 2019). In contrast, the androgenic effects of testosterone in boys during puberty increases lean muscle mass and, in turn, power to weight ratio (Malina et al., 2004). The hormone-dependent hypertrophy of muscle fibres increases sprint speed by improving the ability to rapidly produce force (Viru et al.,1999; Radnor et al., 2018). For instance, researchers have found vertical forces to be significantly higher in post PHV boys compared to mid and pre PHV boys ($p<0.05$) (Rumpf et al., 2015). Accumulatively, research indicates that understanding how growth and maturity effect sprint performance in youth is crucial when investigating young athletes. Limited research has investigated sprinting kinetics and kinematics across maturation in young females compared to their male counterparts (Nagahara et al., 2019; Rumpf et al., 2015; Meyers et al., 2015). Therefore, further research investigating kinetics and kinematics of sprint performance across maturation in females is warranted.

The effect of training on sprinting in youth

In addition to natural development of sprinting, strength training (ST) and plyometric training (PT) have been shown to improve speed-related factors in young men (Rumpf et al., 2012; Wong et al., 2010; Lloyd et al., 2016a). For example, studies have reported both ST and PT to be effective in improving sprinting speed over short distances (0-30 m) in boys across maturation (Christou et al., 2006; Contreras et al., 2017; Prieske et al., 2016; Diallo et al., 2001; Kotzamanidis et al., 2005; Lloyd et al., 2016a; Coutts et al., 2004; Wong et al., 2010). However, limited studies to date have investigated the effect of ST and PT on sprinting performance in young females (Hopper et al., 2017; Hammani et al., 2019; Bogdanis et al., 2019; Chaabene et al., 2019; Myer et al., 2005; Siegler et al., 2003). More specifically, very few studies have investigated the effects of ST and PT alone on sprinting speed in young females, particularly ST (Chaabene et al., 2019; Hammani et al., 2019; Bogdanis et al., 2019; Gonzalez-Garcia et al., 2019). In addition, no previous study has compared the effects of ST vs. PT and different types of PT such as horizontal training (HT) vs. vertical training (VT) on sprinting kinetics including Force (*Fo*), power max (*Pmax*), velocity max (*Vmax*), theoretical velocity (*Vo*), and 0-30 split time in the youth population.

Purpose

The purpose of this research was to better understand the effects of natural development and training on sprint kinetics, kinematics and speed in young female athletes. To this end, two literature reviews, two descriptive studies and two intervention studies were constructed. The specific aims of these 6 chapters were to:

1. Review previous research on the natural development of sprinting kinetics, kinematics and performance in young female athletes.
2. Review previous research on the effects of ST and PT on sprint speed in young female athletes and provide practical recommendations.

3. Determine the reliability of sprinting kinetics using a radar gun in young female athletes.
4. Examine the kinetics and kinematics of sprinting speed in young females across maturation and their relationship with maximal velocity.
5. Investigate the effects of ST and PT and compare the two training methods on sprinting speed, isomeric strength and horizontal jump distance in young female athletes.
6. Compare the effects of HT versus VT and compare the two training methods on sprinting speed, isometric strength, vertical jump height and horizontal jump distance in young female athletes.

Originality of the thesis

Previous research has investigated the kinetics and kinematics of sprinting speed, and the interaction of ST and PT on sprinting speed, in youth (Rumpf et al., 2015; Meyers et al., 2015; Meyers et al., 2016; Lloyd et al., 2016a; Contreras et al., 2017; Asadi et al., 2018). However, this research has been mostly conducted in males, with little attention given to the female population. (Colyer, Nagahara, Takai, & Salo. 2020; Nagahara et al., 2019; Hammami et al., 2019; Myer et al., 2005; Siegler et al., 2003; Hopper et al., 2017). Given the differences in timing of growth (PHV), hormonal levels (testosterone in males vs. oestrogen in females) and physiology (muscle size, fibre composition, tendon stiffness) exist between the genders, research that accounts for these differences is warranted (Malina et al., 2004; Viru et al., 1999; Radnor et al., 2018). More specifically, research that investigates sprinting kinetics and kinematics in young females, including *Fo*, *Pmax*, *Vmax*, *Vo,* step length, step frequency, contact and flight time, is required to elucidate the natural development of sprinting across maturation in this cohort.

With regards to the effect of ST and PT on sprinting, most studies have either combined both forms of training (ST and PT) or investigated the effects of just one form of training on sprinting speed (Siegler et al., 2003, Myer et al., 2005; Hopper et al., 2017; Bogdanis et al., 2019; Hammami et al., 2019; Chaabene et al., 2019). No research to date has compared the effects of ST vs. PT, and compared various forms of PT such as HT vs. VT on sprinting speed in young females. Furthermore, most studies in the youth population that investigated the role of ST and PT have incorporated sprint time (with split times) as the only outcome measure and did not consider sprinting kinetics such as *Fo, Vmax,* and *Pmax.* Due to biological variances in growth, maturation and individual competence, it is important to compare the effectiveness of various training methods on sprinting speed in this cohort. In addition, measuring sprinting kinetics such as *Fo, Vmax* and *Pmax* can provide more insights into sprinting and can help with specific training interventions to improve overall sprinting performance in the youth population. However, very little evidence in the scientific literature exists on the kinetics and kinematics of sprinting across maturation and the effects of ST and PT on sprinting kinetics in young females.

Specifically:

1) No reviews exist on kinetics and kinematics of sprinting in young females that has incorporated biological age across maturation as opposed to chronological age.
2) Limited reviews have investigated the effects of ST and PT on sprinting speed in young females, particularly ST.
3) No study has determined the reliability of sprinting kinetics in young females using a radar gun.
4) No study has investigated sprinting kinetics and kinematics comprehensively in mid and post PHV girls.
5) No study has compared the effects of ST vs. PT on sprinting kinetics.
6) No study has compared the effects of HT vs. VT on sprinting kinetics.

Structure of the thesis

The thesis is comprised of nine chapters (Figure 1). All chapters except for the first and eight are written in the format of the respective journal due for submission. Chapters 2-7 begin with a preface that elucidates how each chapter linked to the next in the larger narrative.

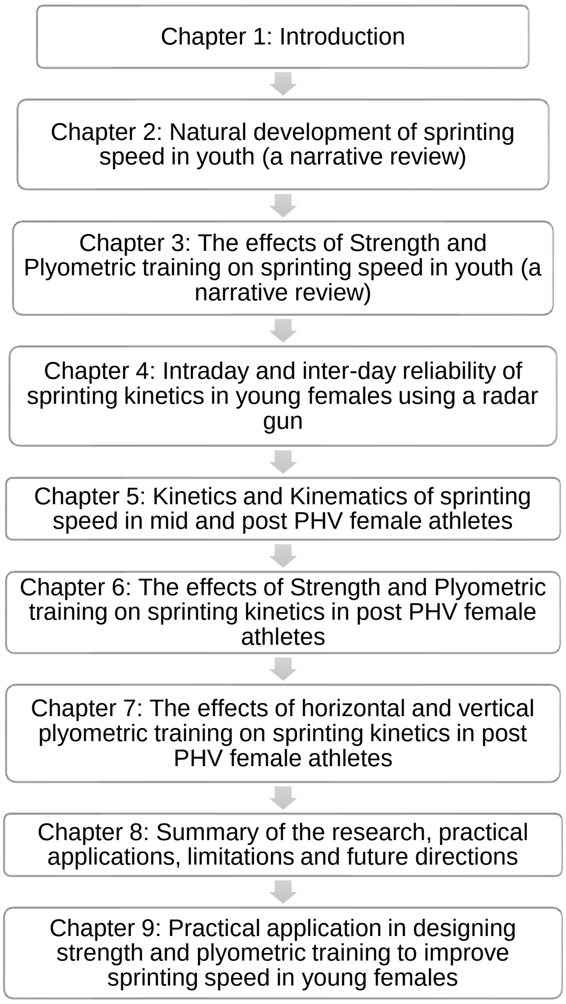

Figure 1: Thesis Organisation

Chapter 2 and 3 review the natural development of sprinting kinetics and kinematics and the effects of ST and PT on sprinting speed in youth, particularly young females respectively. Chapter 4 establishes the reliability of sprinting kinetics using a radar gun in young females before it was incorporated in the following chapters. Chapter 5 incorporates a cross-sectional approach to investigate the kinetics and kinematics of sprinting speed across maturation. Chapter 6 and 7 conducts acute (7 weeks) intervention trials to compare the effects of ST vs. PT, and the effects of HT vs. VT on sprinting kinetics respectively. Chapter 8 provides an overall summary, practical applications and limitations of the research presented, and directions for future research. Finally, chapter 9 provides practical training strategies for practitioners to develop sprinting speed in young females based on the findings of this thesis.

Chapter 2: Natural development of sprint speed in youth: a narrative review

Introduction

Boys and girls tend to show similar sprinting speed during the first decade of life (Borms, 1986; Malina et al., 2004), with a period of accelerated change between 5 and 9 years of age (Borms, 1986; Viru et al., 1999). Speed increases in this age group with the development of the central nervous system and subsequent improvements in coordination (Borms, 1986; Viru et al., 1999). However, from the age of 12 years, increases in sprinting speed slow considerably in girls compared to boys (Whitall, 2003). This disparity is largely due to maturational changes in body size and composition (Beunen & Malina, 1988; Butterfield et al., 2004), driven largely by hormonal changes. Because sprinting is heavily influenced by the stretch-shortening cycle (SSC) (Radnor et al., 2018), the physiological determinants of the SSC, including muscle size, fibre composition, and connective tissue/tendon stiffness (Tillin et al., 2013; McLellan et al., 2011., 2001; Bell et al., 1980; Lexell et al., 1992; Lazaridis et al., 2010), are also important to consider. Therefore, this chapter will review the differences in body composition, muscle size, fibre composition, connective tissue stiffness, growth and maturation in boys and girls with regards to sprinting performance. The chapter will then review two models proposed by previous researchers to optimise sprinting performance in boys and girls and, finally review the changes in sprinting kinetics and kinematics across maturation in the youth population.

Body size and composition

Insulin-like growth factor 1 (IGF-1), an important growth hormone in children, peaks during early adolescence. This anabolic hormonal surge occurs at approximately 12-13 years in girls and 15-16 years in boys (Underwood & Van Wyk, 1985). The anabolic factors can influence the development of muscle tissue hence affecting muscle strength, speed, and power around puberty in girls (Viru et al., 1999). However, this period coincides with sexual maturation in girls, which results in an increase in adipose tissue compared to their male counterparts (Viru et al., 1999; Malina et al., 2004). This can particularly impact movements during which body mass is supported, for example, running and jumping activities (Viru et al., 1999). In contrast, the androgenic effects of testosterone during puberty increases lean muscle mass in boys, which can positively impact weight to power ratio (Malina et al., 2004). Therefore, the differences in the interaction between hormonal changes and sexual maturation may provide an advantage to boys over girls when it comes to sprinting.

Significant changes in body size occur as a natural response to growth during early adolescence. Peak weight velocity (PWV; the greatest rate of change in body mass) reaches 8.3kg/year in girls at about 12.5 years of age (Barnes, 1975). In boys, peak gains in weight are similar but experienced at a relatively later age (i.e., 14 years) (Barnes, 1975). Similarly, the maximum rate of linear growth, defined as PHV (Brown, Patel, & Darmawan, 2017), tends to occur at 12 years of age in females, approximately 6-12 months before the onset of puberty. During PHV, changes in height average of 8 centimetres (cm) per year, with a range of 6-10.5 cm (Hoffman,1997; Kreipe,1994; Needleman, 2004). Boys reach PHV at approximately 14 years of age, with average gains in height ranging from 7-12 cm (Hoffman,1997; Kreipe,1994; Needleman, 2004).

Rapid increases in PHV and PWV can affect physical competencies, including sprinting (Malina et al., 2004). For example, previous research has shown a positive relationship between standing height and sprint speed in prepubertal boys, and leg length and sprint speed in post-pubertal boys (Meyers et al., 2017a). The positive association between height, leg length and sprint speed can be explained by the relationship between the distance the centre of mass travels after the foot hits the ground (i.e., contact length) and an increase in step length that occurs naturally as a result of growth (Meyers et al., 2017a; Lloyd et al., 2016b).

Children also experience significant changes in body composition during puberty (Patel, Pratt, & Greydanus,1998; Roemmich, & Rogol,1995). For instance, both fat mass (FM) and fat-free mass (FFM) increase between 9 and 15 years of age in girls and boys (Malina et al., 2004). However, due to the development of secondary sex characteristics (e.g., wider hips, breast development), a consequence of increased growth hormone secretion, deposits of fat mass are significantly higher in girls with an average of 7.1kg compared to 3.1 kg in boys (Malina et al., 2004). Moreover, proportionately more body fat is concentrated in the lower body of girls (Papai et al., 2012). The increase in body mass may inhibit force production in girls particularly during sprinting, as based on Newton's second law of motion, the greater the body mass the greater the acceleration required to displace the body.

Body fat mass has also been shown to have a negative influence on sprint speed in youth athletes (Meyers et al., 2017a). For example, Meyers et al. (2017a) reported that body mass was negatively related to 30 sprint speed in both pre and post PHV boys ($r = -0.03$; $p < 0.05$). More specifically, in pre PHV boys, body mass had a negative influence on step frequency ($r = -0.48$). In post-PHV boys, body mass negatively influenced step length ($p < 0.05$, $r = -0.54$) (Meyers et al., 2017a). Therefore, it is important to assess changes in height, weight, and body composition particularly during the time of puberty as it can affect sprinting performance in the youth population.

Higher fat deposition in girls, a result of increasing oestrogen levels (Malina et al., 2004), may also affect sprinting kinetics and kinematics (Beunen & Malina,1988; Butterfield, Lehnhard, Lee, & Coladarci, 2004; Malina et al., 2004). Nagahara et al. (2019) investigated change in sprinting performance in Japanese girls between the ages of 7.0 and 15.3 years. The findings showed that girls >12.7 years became slower every year (-0.09 m/s) compared to girls <12.7 years (0.24m/s). Furthermore, the older girls had a plateau in step length and a reduction in ground reaction forces (GRFs) compared to the younger girls (Nagahara et al., 2019). Due to an increase in fat mass as girls mature, relative force production and step length can be considerably reduced, negatively impacting sprinting performance. Apart from body size and composition, there are other physiological differences between the genders that can impact sprinting performance such as SSC, muscle size, fibre composition, and muscle tendon stiffness.

The stretch-shortening cycle

SSC is characterised by an eccentric ‘stretching’ action before subsequent rapid concentric action. Sprinting, jumping and throwing utilises the SSC (Lloyd et al., 2015). It has been reported that this action (eccentric stretch before concentric) is more useful in improving the performance of the final concentric phase compared to an isolated concentric action (Nicol et al., 2006; Flanagan & Comyns, 2008). For example, jump height was reported to increase by 1-5% when preceded by countermovement (pre-stretch action) in young males (Lloyd et al., 2009). Furthermore, SSC can be categorised into fast and slow action based on ground contact time. Ground contact time shorter than 250ms is generally classified as fast SSC and ground contact time above 250ms is considered slow SSC (Flanagan & Comyns, 2008; Turner & Jeffrey, 2010). Sprinting can be considered as a fast SSC activity since the ground contact time is lower than 250ms. The function of the SSC is determined by several physiological variables, including muscle size, fibre composition, and connective tissue/tendon stiffness that may vary between genders (Radnor et al., 2018).

Muscle size

It is believed that increases in muscle size can contribute towards the improved capacity to produce force which leads to greater performance outcomes during SSC activities (Radnor et al., 2018). Muscle size increases with growth and biological maturation with the ability produce higher force during both concentric and eccentric actions (O’Brien et al., 2010a; Kubo et al., 2001; O’ Brien et al., 2010b). More specifically, in isolated concentric and eccentric muscle actions, muscle size has been associated with quadriceps and hamstrings concentric strength and hamstring eccentric strength (Morse et al., 2008). Greater concentric strength during SSC actions can contribute towards greater impulse and rate of force development hence providing superior performance during sprinting and jumping tasks (Tillin et al., 2013; McLellan et al., 2011). In addition, as muscles increase in size during growth, the higher forces during the eccentric phase of sprinting and jumping may result in an increased storage of elastic energy (Komi, 2000). Therefore, increases in lean muscle mass and size in boys can be an advantage for SSC based activities such as sprinting compared to their female counterparts.

Fibre type composition

In addition to muscle size, fibre type composition can also play an important role in sprinting (Bell et al., 1980). Type 2 muscle fibres help to improve the ability to rapidly produce force resulting in greater benefit from the SSC compared to type 1 fibres (Radnor et al., 2018). It is reported that type 1 fibres decrease from approximately 65% at age 5 years to 50% at age 20 years (Lexell et al., 1992). However, limited longitudinal data have reported that gender differences in fibre type can be evident as the adolescent transition towards adulthood. More specifically, type 1 fibre percentage tends to increase in women (51 ± 9% to 55 ± 12%) and decrease in men (55 ± 12% to 48 ± 13%) between the ages of 16 and 27 years (Bell et al., 1980; Lexell et al., 1992). Therefore, the ability to produce force rapidly in females can be limited hence affecting sprinting performance compared to their male counterpart, post PHV.

Muscle and tendon stiffness

Apart from muscle size and fibre type composition, tendon stiffness has also been documented to have a positive influence on sprinting performance in children (Lambertz et al., 2003). Increased tendon stiffness leads to shorter braking forces, reduced ground contact times and greater electromyographic activity that can be useful during sprinting (Lazaridis et al., 2010). Previous studies have reported that males have a higher level of stiffness compared to females in the patella and Achilles tendon (Onambele et al., 2007; Hicks et al., 2013). However, there are limited studies that have investigated the difference in tendon stiffness in boys and girls across maturation (O'Brien et al., 2010b). Therefore, understanding how growth, maturity and physiological mechanism associated with SSC affects sprinting kinetics and kinematics is crucial when investigating young females.

Assessment of growth and maturation

There are several ways to assess the growth and biological maturity of a child. The most popular clinical method utilises a plain X-ray of the left hand, wrist or knee and classifies children according to their skeletal age (Malina et al., 2004; Carling, Le Gall, Reilly, & Williams, 2009; Johnson, Doherty, & Freemont, 2009). Unfortunately, this method requires expensive equipment and an experienced investigator, thus is impractical for young athletes (Harrison, 2013). The Tanner Staging method, which classifies sexual maturity based on pubic hair development, has also been used widely in the literature (Tanner & Whitehouse, 1976; Faigenbaum et al., 1993; Conte et al., 2017). However, classification requires athletes to self-assess, which can affect the reliability of the measures (Rasmussen et al., 2015). For example, a previous study in Danish children (n=898) reported that self-assessment and parental assessment were inaccurate in a substantial number of participants when compared with a clinical examination by trained physicians (Rasmussen et al., 2015). More specifically, half the girls tended to underestimate their exact breast development stage, and one quarter also underestimated their pubic hair. Therefore, suggesting that self-assessment of pubertal maturation can be inaccurate and unreliable.

A cheaper, non-invasive way of assessing maturation is by calculating the estimated years an individual is away from PHV. This method provides a maturity offset value using simple objective anthropometric measures, including leg length, sitting height, weight by height ratio and age (Mirwald, Baxter-Jones, Bailey, & Beunen, 2002; Malina et al., 2004). Years from PHV can be used to characterise changes in body size, body composition and performance relative to changes in height (Malina et al., 2004). Maturity status is determined as pre-PHV (>1 year prior to PHV), circa-PHV (± 1 year from PHV), and post-PHV (> 1 year post PHV) and comparisons of any changes in performance can be made (Harrison, 2013). The Khamis-Roche method is another non-invasive and practical way of assessing maturity and includes three predictor variables: current stature (height), current weight and mid parent stature (mother's height + father's height/2) (Khamis & Roche, 1994).

Past research has incorporated the Mirwald and Khamis-Roche methods effectively to measure growth and maturation (Rumpf et al., 2012; Cumming et al., 2018). For example, Rumpf et al. (2012) used the Mirwald method to investigate sprinting kinetics and kinematics across maturation. Similarly, Cumming et al. (2018) used the Khamis-Roche method to predict adult height in a cohort of young soccer players when investigating the efficacy of bio-banding. It is important to assess growth and maturity in research with youth populations to guide safe and effective applications of training.

Developmental Models

Youth athlete training interventions that consider growth and maturation are essential. To support practitioners in this process, the long-term athletic development model (LTAD) was proposed (Balyi & Hamilton, 2004; Bompa, 1995). The LTAD model attempts to maintain balance between training load and competition throughout childhood and adolescence (Ford et al., 2011). It also proposes specific windows of development, termed “sensitive periods of development” for various components of fitness. When considering speed, the LTAD model suggests two training sensitive periods during childhood (Balyi & Hamilton, 2004), aligned to chronological age. The first period, occurring at 7-9 years in both genders, is aligned to a neurological spurt (Figure 2.1) (Balyi & Hamilton, 2004). According to the LTAD model, a period of accelerated brain development around age 7-9 years improves a child’s ability to acquire the motor skill (Balyi & Hamilton, 2004; Higgs et al., 2008) via improvements in coordination (Cratty, 1986). The second sensitive period, occurring at 11-13 and 13-15 years of age in girls and boys, respectively, reflects a maturational window of opportunity for training (Figure 2.1) driven by hormone-dependent hypertrophy of muscle fibres (Viru et al., 1999; Phillippaerts et al., 2006; Venturelli, Bishop, & Pettene, 2008).

<table>
<tr><th colspan="15">Speed Developmental Age</th></tr>
<tr><th>Chronological Age</th><td>5</td><td>6</td><td>7</td><td>8</td><td>9</td><td>10</td><td>11</td><td>12</td><td>13</td><td>14</td><td>15</td><td>16</td><td>17</td><td>18</td></tr>
<tr><td>Speed 1</td><td colspan="2"></td><td colspan="3"></td><td colspan="9"></td></tr>
<tr><td>Speed 2 (Girls)</td><td colspan="6"></td><td colspan="3"></td><td colspan="5"></td></tr>
<tr><td>Speed 2 (Boys)</td><td colspan="8"></td><td colspan="3"></td><td colspan="3"></td></tr>
</table>

Figure 2.1: Long term Athletic Development (LTAD): Sensitive periods for speed development (adapted from LTAD model, Balyi & Hamilton, 2005)

However, since the LTAD model’s inception it has been critiqued for a lack of scientific rigour as the sensitive periods of development are based on chronological age as opposed to biological growth and maturity (Ford et al., 2011). For example, several factors influence speed throughout childhood, including quantitative changes in muscle cross-sectional area and length, morphological alterations to the muscle and tendon, development of SSC through neuromuscular pathways, and biomechanical factors associated with sprinting (kinetics and kinematics) (Ford et al., 2011; Radnor et al., 2018). Hence, it is important to consider these factors when investigating the potential of speed development in youth across maturation rather than rely completely on the windows of opportunity based on chronological age. It is also important to note that the majority of research investigating speed development in youth populations has been conducted in boys (Rumpf et al., 2015; Meyers et al., 2015; Meyers et al., 2016; Meyers et al., 2017a). As identified above, considering the emergence of distinct differences in physiology between the sexes with maturation, and their subsequent effects on speed, more research investigating the second LTAD window of training in girls is warranted (Papai et al., 2012).

More recently, using existing empirical research, the Youth Physical Development (YPD) model was proposed (Lloyd & Oliver, 2012). The goal of the YPD model was to establish an overall long-term strategy for physical development across childhood and adolescents. In contrast to the LTAD model, the YPD model proposes that all fitness components are trainable throughout development but that the magnitude of change differs based on maturation (Lloyd et al., 2015). More specifically, the YPD model suggests that speed can be trained at any age with a greater emphasis between 5-15 years in females and 5-16 years for males (Lloyd & Oliver, 2012). Furthermore, the model emphasises individualisation of training prescription due to the differences in timing, tempo, and magnitude of maturation between children (Lloyd et al., 2015). For example, it is believed that the training adaptation during pre PHV phase is predominantly neural compared to a combination of neural and hormonal during mid and post PHV phases in both males and females (Lloyd & Oliver, 2012). In young males, it was found that PT was useful in improving sprinting speed during pre PHV but a combination of ST and PT was more effective during post PHV further supporting the YPD model (Lloyd et al., 2016a) However, more research is warranted if the adaption is similar across maturation in young females.

Speed Developmental Age														
Chronological Age	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Girls														
Boys														

Figure 2.2: Youth Physical Development (YPD): Sensitive periods for speed development (adapted from YPD model, Lloyd & Oliver 2012)

Despite their differences, both the LTAD and YPD models suggest that biological maturity should be considered when planning individual components of fitness in youth (Ford et al., 2011; Lloyd & Oliver, 2012). Furthermore, child physiology and how it changes with growth, and between the sexes, is important to understand when prescribing speed training in youth (Oliver et al., 2013; Balyi & Hamilton, 2004).

Determinants of speed: sprint-running performance

Several factors influence sprint performance in youth, including the motions of the body (i.e. kinematics) (Hunter, Marshall, & McNair, 2005; Salo et al., 2011; Meyers et al., 2016), the forces that produce, arrest or modify the motions of the body (i.e., kinetics) (Meylan et al., 2014; Read et al., 2016; Rumpf et al., 2015) and the measurements and proportions of the body (i.e., anthropometry) (Meyers et al., 2016; Meyers et al., 2017b; Lloyd et al., 2016b). Since the anthropometrical factors (PHV, PWV, body composition) have already been discussed in the previous sections, this section will specifically review the kinetics and kinematic associated with sprinting speed in young boys and girls across maturation.

Kinematics

Sprint speed is a product of step length and step frequency (Meyers et al., 2017b). However, the relationship between step length and frequency is not always linear (Meyers et al., 2017b). For instance, research has demonstrated a negative interaction between step length and step frequency in adult sprinters i.e., a longer step length tends to result in a lower step rate (Debaere, Jonkers, & Delecluse, 2013; Hunter et al., 2004; Coh, Milanovic, & Kammiller, 2001). The interaction between step length and step frequency is more difficult to define in youth populations due to changes in natural development (Meyers et al., 2017b). For instance, step length increases throughout childhood and adolescence as a result of changes in leg length associated with growth (Meyers et al., 2016; Schepens, Willems, & Cavagna, 1998). Read et al. (2016) reported a consistent increase in step length among boys who remained pre-PHV and boys moving from pre to post PHV (7.8 and 8%, respectively) compared to step frequency.

Previous research investigating step frequency and flight time indicated that both remain unchanged throughout childhood and in boys of advancing maturity (Schepens et al., 1998; Rumpf et al., 2015; Meyers et al., 2015). Pre-PHV boys tend to be more reliant on step frequency when sprinting (Meyers et al., 2017a), but may lack the motor coordination and strength to orientate, stabilize and apply force through their lower limbs during sprinting (Meyers et al., 2015). Therefore, there may not be any meaningful changes in step frequency and flight time in male youth across maturational levels whereas increases in step length can be observed for boys who have experienced the period of PHV.

Despite a few studies having investigated the effects of change in kinematics on sprint performance in boys, there are currently limited studies in girls. In a recent study by Nagahara et al. (2019), it was found that in young (<12.7 years) Japanese girls, step length increased in by 0.08m/y but plateaued (0.01 m/y) for the older girls >12.7 years. Similarly, researchers have reported no increase in step length with minimal increase in step frequency among Slovakian girls (mean age 13.5 years) (Vanderka & Kampmiller, 2012). However, both aforementioned studies did not consider maturation and biological growth. Based on chronological age, it is difficult to conclude if growth-related factors (e.g., fat mass, PHV) during puberty played a role. Therefore, more research investigating sprinting kinematics in girls across maturation is warranted.

Kinetics

The kinetics (horizontal and vertical forces) of sprint performance have been widely investigated in adults (Brughelli, Cronin, & Chaouchi, 2011; Kuitunen, Komi, & Kyrolalinen, 2002; Nilsson & Thorsrensson, 1989; Nummela, Keranen, & Mikkelsson, 2007). Previous studies report that peak and average force increase proportionately to running speed up to 60% of maximum velocity, then remain relatively constant up to maximum velocity (Kyrolainen et al., 2001; Nilsson & Thorstensson,1989; Brughelli et al., 2011). More specifically, during the acceleration phase, horizontal forces have been shown to significantly increase with increasing speed (Brughelli et al., 2011; Kuitunen et al., 2002; Nummela et al., 2007) and during both braking (i.e., eccentric) and propulsion (i.e., concentric) phases (Kuitunen et al., 2002; Nilsson & Thorstensson, 1989). Peak vertical forces are stable and do not differ between 70 and 100% of maximal velocity (Kuitunen et al., 2002). These studies suggest that horizontal force plays an important role in sprinting, particularly during the initial phases of acceleration to overcome inertia.

While much research has investigated how kinetics effect sprint speed in adults, there is a paucity of research investigating over-ground sprinting in youth (Rumpf et al., 2015, Meyers et al., 2015; Meyers et al., 2016; Meyers et al., 2017b). Studies utilizing non-motorized treadmills suggest that maximal force and power may be important predictors of sprint performance in boys across maturation (Meylan et al., 2014b; Rumpf et al., 2015). More specifically, vertical power has been shown to have a large impact on sprint performance in pre- and mid-PHV boys (Meylan et al., 2014b). Cross-sectional and longitudinal data collected in boys has also shown that vertical stiffness, relative maximal force, and relative leg stiffness contribute to sprint performance (Read et al., 2016; Lloyd et al., 2016b).

Sprint kinetics may differ between sexes during childhood and adolescence due to changes in maturity status and growth (Rumpf et al., 2015). For instance, during puberty, higher levels of circulating androgens and growth hormones in boys (Forbes et al., 2009; Ramos Frontera, Llopart, & Feliciano, 1998; Round, Jones, Honour, & Nevill, 1999) increases force production (Rumpf et al., 2015). However, an increase in muscle mass and force-generating capacity can be limited in girls during this time due to the reduced anabolic effect of oestrogen. This difference has been shown to influence strength and power in general by decreasing connective tissue stiffness that can negatively affect sprinting kinetics in girls (Chidi-Ogbolu, & Baar, 2019; Malina et al., 2004).

There are limited studies investigating kinetics in young females (Nagahara et al., 2019; Coyler et al., 2020). Nagahara et al. (2019) examined age-related differences in sprinting kinetics in (7.0-15.3 years old Japanese girls) and found an increase in propulsive impulse of 0.024 Ns/y in the younger Japanese girls compared to -0.010 Ns/y in the older girls. However, the authors did not assess maturity status, choosing to divide the girls into two groups based on chronological age (younger <12.7 years and older >12.7 years). Even though the older girls in this study were significantly quicker than the younger girls for 25 m and 50 m sprints ($p<0.05$), the propulsive forces during acceleration were significantly greater in younger girls compared to the older girls. This is probably due to greater growth rates in height (6.3 cm/y) in the younger girls and increases in fat mass with maturation in the older girls who might have impaired relative force production during acceleration phase (Nagahara et al., 2019).

In addition, another recent study investigated GRFs related to sprinting speed in pre PHV untrained boys and girls (Coyler et al., 2020). It was reported that higher velocities were attributed to greater antero-posterior GRFs across shorter ground contacts in pre PHV boys (4.5-3.5 years before PHV) compared to (5.5-4.5 years before PHV), effect size (ES): ± 90% CI = 1.63 ± 0.69) (Colyer et al., 2020). In comparison, the increase in maximal velocities in pre PHV girls (2.5-1.5 years before PHV) compared to (1.5-0.5 years from PHV) were not attributed to the increase in GRFs but rather due to longer ground contact time (ES: ± 90% CI = 1.00 ± 0.78). This study suggested that boys undergo a period of accelerated development in sprinting performance around 4.5-5 years before their PHV whereas rapid development in girls was observed 1.5-2 years before PHV. Furthermore, force-generating capacity in boys can help them better utilise SSC and more effectively reverse braking forces compared to their female counterparts (Colyer et al., 2020).

In summary, there is no difference in sprinting performance between boys and girls during the first decade of life. However, things change during puberty. Due to the influence of oestrogen, girls tend to increase body fat mass and reduce connective tissue stiffness compared to the boys, negatively impacting sprinting speed. However, few studies investigating the effect of kinetics and kinematics of sprinting speed in youth populations have included girls (Nagahara et al., 2019; Coyler et al., 2020). More research in this area is warranted, particularly studies that assess maturation. Studies that examine more specific kinematic and kinetic variables are also required.

Chapter 3: The effects of strength and plyometric training on sprinting speed in young males and females: a narrative review

Preface

Chapter 2 revealed significant differences in body composition and size, and the physiology of the SSC, between boys and girls. Furthermore, these differences change with maturation, effecting kinetics, kinematics and overall sprinting performance. However, the majority of previous research addressing these areas has been conducted in boys. Considering that girls develop in their own unique way, more research examining the kinetics and kinematics of sprinting in this population is urgently required. What is clear is that training above and beyond natural development can improve sprinting kinetics and kinematics. Therefore, chapter 3 aimed to review the effects of strength and plyometric training on sprinting speed in the youth population, with a focus on young females.

Introduction

Strength and plyometric training have been shown to improve speed-related factors in young men, including horizontal and vertical force, step frequency and step length (Rumpf et al., 2012; Meyers et al., 2017b; Meylan et al., 2014b). For example, ST has been shown to improve sprint speed in boys across maturation due to an improved ability to generate force (Christou et al., 2006; Contreras et al., 2017; Prieske et al., 2016; Meylan et al., 2014b; Wong et al., 2010; Lloyd et al., 2016a). However, there is a paucity of research to date that has investigated the effects of ST and PT on sprint speed among young females (Myer et al., 2005; Siegler et al., 2003; Hopper et al., 2017). More specifically, most studies have investigated a combined effect of ST and PT on sprint performance (Myer et al., 2005; Siegler et al., 2003; Hopper et al., 2017). Therefore, further investigation is warranted.

Strength training in boys

Research shows that an increase in strength and force production correlates with enhanced sprinting speed performance in youth (Christou et al., 2006; Meylan et al., 2014b). More specifically, ST has been shown to improve sprinting speed in boys across maturational levels (Christou et al., 2006; Contreras et al., 2017; Prieske et al., 2016). Christou et al. (2006) reported significant changes in 30 m sprint time after 16 weeks of machine-based ST in male soccer players aged 13.80 ± 0.40 years ($p<0.05$). Similarly, Contreras et al. (2017) found 6 weeks of horizontal free weight ST in boys aged 15.49 ± 1.16 years improved 10 m (*d*=0.55) and 20 m (*d*=1.14) sprint times, respectively. In addition, numerous studies have reported significant changes in sprinting performance after 8-13 weeks of ST training in post PHV boys (Prieske et. al., 2016; Chelly et al., 2009; Coutts, Murphy, & Dascombe, 2004; Kotzamanidis et al., 2005). Therefore, it seems that ST involving both free weights and machines can positively influence sprinting speed in young boys.

Regression modelling suggests that a 10% improvement in force production can result in a 1.6-4.2% increase in sprint performance in boys (Lloyd et al., 2016b; Meylan et al., 2014b). More specifically, it was reported that 3% change from post-mid PHV and 5% change from post to pre PHV in 1RM strength had a moderate and large effect respectively on sprint time (Meylan et al., 2014b). However, is not as simple as the more load the better, particularly when using certain types of training interventions. For instance, research shows that when using sled pulling, some loading regimes are more effective than others at increasing sprint speed. Indeed, in a study examining the effects of 6 weeks of resisted sled tow training (2.5-10% of body mass) in boys, no improvements in sprinting speed were found in the pre PHV group (Rumpf et al., 2015). However, the same study reported significant improvements in average velocity ($p<0.05$), average step rate, relative stiffness, average power, peak horizontal force and sprint time in the mid and post PHV groups (Rumpf et al., 2015). These findings suggest that ST may be more useful in improving sprinting performance in mid and post PHV boys than pre PHV boys (Rumpf et al., 2013; Rumpf et al., 2015).

Importantly, ST is more effective at improving sprinting speed in some male youth populations when combined with other types of training (Kotzamanidis et al., 2005; Andrejic, 2012). For example, Lloyd et al. (2016a) showed that a combination of ST and PT is more effective at improving 10 and 20 m sprinting speed in post PHV boys (*d*=0.62, *d*=0.50 respectively) compared to pre PHV boys (*d*= 0.32, *d*=0.31) (Lloyd et al., 2016a; Radnor, Lloyd, & Oliver, 2017). Following their growth spurt, boys experience morphological changes that enhance force-generating capacity. This can be attributed to an increase in muscle size, fibre composition and tendon stiffness along with an increase in neural adaptation with maturation (Radnor et al., 2018; Malina et al., 2004). Accordingly, combining ST and PT may be required to optimise sprinting speed in post PHV boys (Lloyd et al., 2016a).

Strength training in girls

To date, little research has investigated the effects of ST on sprinting speed in girls. Myer et al. (2005) reported significant changes in 9.1 m sprint time among post-PHV girls when ST was combined with PT ($p<0.05$). Similarly, Siegler et al. (2003) also reported significant changes in 20 m sprint time after 10 weeks of ST in post PHV girls ($p<0.05$). However, both the aforementioned studies combined ST with PT. A more recent study investigated the effects of two different strength exercises on sprinting speed in adolescent female, sub-elite soccer players (Gonzalez-Garcia et al., 2019). Participants performed either hip thrust or back squat twice a week for 7 weeks using a load progressively increased from 60-90% IRM. The findings showed more improvement in 10 and 20 m sprinting speed in the group that performed the hip thrust exercise (d=0.7 and d=0.46, respectively) (Gonzalez-Garcia et al., 2019). However, given a low sample size across the groups (n=8), the effect of ST alone on sprinting speed in this population needs further investigation.

Plyometric training in boys

It has been well documented that PT predominantly involves rapid movements of the lower body (e.g., jumping and bounding). Mechanistically, it emphasizes the coupling of eccentric and concentric muscle actions along with the development of the SSC (Matavulj et al., 2001). Over time, the nervous system adapts to the plyometric stimulus and increases power production (Diallo et al., 2001; Kotzamanidis, 2006). Sprint running utilises a similar SSC response to plyometrics (Cormie, McGuigan, & Newton, 2011; Markovic et al., 2007). Therefore, PT can be useful in utilising the SSC response to positively influence sprint performance. (Lloyd et al., 2016a). For example, 6 weeks of combined horizontal (HT) and vertical (VT) PT has been shown to elicit better sprint performance in pre-PHV soccer players compared with ST alone

(Ramirez-Campillo et al., 2015b; Lloyd et al., 2016a). The influence of jumping power on sprinting speed has been well documented previously (Meylan et al., 2014b; Lloyd et al., 2016a). Regression modelling has shown that a 10% improvement in power during jumping may elicit a 2% improvement in sprinting performance in youth across maturation (Meylan et al., 2014b). More specifically, it was found that 3.4% changes from post to pre and 4.3% from post to mid PHV in peak power had a moderate and large effect respectively on sprint time (Meylan et al., 2014b).

Vertical stiffness also plays an important role in sprint performance (Meyers et al., 2017b). Greater stiffness improves the ability of the body to tolerate and overcome gravitational forces effectively (Nagahara & Zushi, 2017). Vertical stiffness can help reduce ground contact time and increase step frequency and as a result can positively influence sprinting speed (Meyers et al., 2017b). Regression modelling has shown that an 8% increase in vertical stiffness can result in a 1.3% increase in the maximal sprinting speed in youth (Lloyd et al., 2016b). Previously, researchers have reported 8% improvements in relative vertical stiffness with just 4 weeks of PT in pre and post PHV boys (Lloyd et al., 2012). Therefore, PT may play a significant role in enhancing vertical power and stiffness and improve sprinting performance in young males, accordingly (Meylan et al., 2014b, Lloyd et al., 2016a).

PT is most effective for improving sprint times in pre-PHV boys (Diallo et al., 2001; Kotzamanidis, 2006; Lloyd et al., 2016a). The high neural demand of PT may provide a stimulus that coincides with the natural adaptive response of late childhood (Lloyd et al., 2016a). For example, Diallo et al. (2001) reported significant changes in 20 m sprinting speed after 10 weeks of PT in young male football players aged 12-13 years. Similarly, Lloyd et al. (2016a) and Kotzamanidis (2006) also reported significant changes in 20 and 30 m sprint speed in prepubertal boys after 6 and 10 weeks of PT respectively ($p<0.05$; $p<0.01$).

Plyometric training in girls

Few studies have looked at how PT affects sprinting speed in females (Myer et al., 2005; Siegler et al., 2003; Hopper et al., 2017; Hammami et al., 2019; Chaabene et al., 2019; & Bogdanis et al., 2019). Most of these studies showed that, when ST and

PT were combined, a significant improvement ($p<0.05$) in sprinting speed resulted (Table 3.1). Three of the aforementioned studies also investigated the effect of PT alone on sprinting speed (Hammami et al., 2019; Chaabene et al., & Bogdanis et al., 2019). The findings showed that PT is useful in improving sprinting speed in young females across maturation (pre and post PHV). However, while previous researchers have investigated the effects of PT on sprinting speed in pre (Bogdanis et al., 2019) and post PHV female athletes (Chaabene et al., 2019), no study has compared the effects of different types of PT on sprinting speed in this population. A recent systematic review reported HT to be most effective in enhancing horizontal performances such as sprinting and jumping compared to VT in young and adult males (Moran et al., 2020). However, none of the studies in the review included females. Given the limited evidence to date in this area, more research examining the effects of different types of PT such as HT vs. VT on sprinting speed in young females is warranted.

Table 3.1: The effect of strength and plyometric training on sprinting speed in youth

Authors	Participants	Speed Performance Indicators	Intervention	Results
Andrejic, 2012	11 young male basketball players, age 12.50 ± 0.50 years	20 m	Combined (strength training: body weight and rubber cord full body exercises, 1 set of 8-25 repetitions, twice per week, for 6 weeks) and plyometric training: 1 set of 4-6 repetitions, twice per week, for 6 weeks	20 m -5.30% (p <0.05)
Asadi et al., 2018	10 pre PHV male, age 11.50 ± 0.80, 10 mid PHV 14.00 ± 0.70, and post PHV 16.60 ± 0.60 soccer players	20 m	Depth jump (20, 40, & 60 cm), 2 sets of 10 repetitions, twice a week for 6 weeks	Pre PHV (ES= -0.12), Mid PHV (ES=-0.58), Post PHV (ES= -0.66)
Bogdanis et al., 2019	33 young female gymnasts, age 8.10 ± 0.70 years	10 m, 20 m	Plyometric training: 2 set of 6-30 repetitions, twice a week for 8 weeks	10 m (*d* =1.10, p<0.01) 20 m (*d* = 1.14, p <0.01)
Chaabene et al., 2019	12 Handball players, age15.90 ± 0.20 years	5 m, 10 m, 20 m	Plyometric training: bilateral ankle hops and counter movement jumps, 4-6 sets of 10 repetitions, twice a week for a total of 8 weeks	5 m (ES = 0.81), 10 m (ES = 0.84), 20 m (ES = 0.56)
Chelly et al., 2009	11 young soccer players age 17.00 ± 0.30 years	40 m	Back half squat 70-90% RM, 2-7 repetitions, twice a week for 8 weeks	7.84 ± 0.53 to 8.77± 0.44 (p<0.05)
Christou et al., 2006	9 male soccer players, age 13.80 ± 0.40	10 m, 30 m	Strength: 2-3 sets of 8-15 repetitions @ 55-80% of 1RM, twice a week for 16 weeks, machine-based weight training	30 m (2.5%, p<0.05)
Contreras et al., 2017	13 adolescent males, age 15.49 ±1.16	10 m, 20 m	Strength: Hip thrusts 4sets of 6-12 repetitions @6-12RM loads, twice a week for 6 weeks	Hip thrust 10 m (*d*=0.55) & 20 m (*d*=1.14)
Coutts et al., 2004	21 male young rugby players, age 16.70 ± 1.10 years	10 m, 20 m	Strength: full body 3-6 sets of 4-16 repetitions @55-88.5%, thrice a week for 12 weeks	10 m-0.08 (p<0.05) 20 m-0.08-00.09 (p<0.05).

Diallo et al., 2001	10 young male football players, age 12-13 years	20 m, 30 m, 40 m	Plyometric: jumping, hurdling, and skipping, 3 times a week for a total of 10 weeks	20m ($p<0.05$)
Franco-Marquez et al., 2015	20 male soccer players, age 14.70 ± 0.50 years	10 m, 20 m	Combined and Power. Strength: Smith machine bar full squats with low loads (45-60% IRM, 2-3 sets of 4-8 repetitions) performed 2 times a week for 6 weeks. Power: Jumps, sprints, triple jump performed twice a week for 6 weeks	10-20 m and 20-30 m sprint time ($p<0.05$, -1.30 & -1.10 90% cl respectively)
Gonzalez-Garcia et al., 2019	8 adolescent female soccer players, age 16.82 ± 1.56 years	10 m, 20 m	Hip thrust 60-90% IRM twice a week for 7 weeks	10 m (d=0.70), 20 m (d=0.46)
Gonzalo-Skok et al., 2019	18 young male basketball players (9 unilateral, 9 bilateral), age 13.20 ± 0.70 years	25 m (5 &10 m splits)	Unilateral plyometric: horizontal training twice per week for a total of 6 weeks, 60-100 jumps per session	Unilateral: 5m split ES (cl 90%)-0.78(0.45;1.11), 10m split ES (cl 90%)-0.77(0.45;1.1), 25m ES (cl 90%)-0.30(0.17;0.42)
			Bilateral plyometric: vertical training twice per week for a total of 6 weeks, 60-100 jumps per session	Bilateral: 5m split ES (CL90%)- 0.28(-0.02;0.58), 10m split ES (CL90%)- 0.8 (0.0;1.6)
Hammani et al., 2019	21 young female handball players 13.50 ± 0.30 years	5 m, 10 m, 20 m, 30 m	Lower body power: hurdle jumps, upper body power: dynamic push-ups with 60-80 contacts twice a week for 9 weeks.	5 m (d=1.09, $p<0.001$); 10 m (d=0.81, $p<0.001$); 20 m (d=1.16, $p<0.001$); 30 m (d=3.06, $p<0.001$).
Hopper et al., 2017	13 junior female netball players, age 12.08 ± 0.95 years	20 m	Neuromuscular training- Plyometric: 3 sets of 5 repetitions for 6 weeks including vertical and horizontal jumps, three times per week	10-and 20-m ($p\leq0.05$, g >-1.2)
			Strength: 3sets of 8 repetitions full body free weights for 6 weeks, three times per week. Session RPE: 3-8	
Kotzamanidis 2006	15 boys, age 11.10 ± 0.50 years	10 m, 20 m, 30 m	Plyometric training -60-100 jumps per session for a total of 10 weeks performed twice a week	0-30 m, 10-20 m & 20-30 m ($p<0.05$)

Kotzamanidis et al., 2005	12 boys, age 17.00 ± 1.10 years	30 m	Combined strength and sprint training for 9 weeks, thrice a week. Strength training included free weight and machine exercises 6-RM 3RM loads, 4 sets and 4-6 30 m sprints with 3 minutes recovery	30 m ($p<0.01$)
Lloyd et al., 2016a	80 males, 40 Pre-PHV 12.7 ± 0.3, & 40 post-PHV 16.30 ± 0.30	10, 20 m	Strength: 3 sets of 10 repetitions (Barbell back squat, lunge, step up and leg press) @10RM loads, 5% increase each week. Twice per week for 6 weeks Plyometric: jumping, landing activities (bilateral and unilateral) 74-88 foot contacts per session, twice per week for 6 weeks	Pre PHV (plyometric training) 10m (*d*=0.38) Post PHV combined training (*d*=0.62) Pre PHV (plyometric training) 20m (*d*=0.45) Post PHV (combined training) 20m (*d*=0.50)
Myer et al., 2005	41 high school female athletes (soccer and volleyball) 15.30 ± 0.90 years	9.1 m	Neuromuscular training (strength, plyometric, core and speed) Strength: free weight and machine, 8-15 repetitions, 1-2 sets thrice per week for a total of 6 weeks Plyometric: jumps, hops, 6 repetitions or 10-15s, 1 set, twice per week for a total of 6 weeks Core-stable and unstable 4-30 repetitions/20-55s, 1-2 sets twice a week for a total of 6 weeks Speed: resistance speed, <15s, 1-2 sets twice a week for a total of 6 weeks	9.10m (trained females) (4.05%, $p<0.001$).
Prieske et al., 2016	20 male soccer players, age16.60 ±1.10 years	10 m, 20 m	Strength: core strength training on stable surface (floor, bench) and core stability training on unstable surface (stability trainer, thera-band, Swiss balls), 2-3 times for 9 weeks	10-20 m sprint time (3%, $p<0.001$, *d*=2.56)
Siegler et al., 2003	17 female high school soccer players, 16.49 ± 0.91	20 m	Strength: Lower body free weight and machine exercises @ 10-15 RM, 3 sets twice a week for 10 weeks Plyometric: Jumps and skips, thrice a week, 2-3 sets for 10 weeks	20 m sprint (-0.10± 0.10 seconds, $p=0.0003$)

Wong et al., 2010	28 male soccer players, age 13.50 $\pm$ 0.70 years	10 m & 30 m	Combined strength and power. Strength: upper and lower body strength (free weights), 5-10 repetition of 3 sets, 2 times a week for 8 weeks Power: Olympic lifting variations and single leg and double leg hops, 5-8 repetitions of 3 sets, twice a week for 4 weeks	10 & 30m (ES: 0.57 and 0.94 respectively)

*****Cl- Confidence limit, ES- Effect size, *g*- Hedge's g, *d*- Cohen's *d*, p- Probability value, PG- Plyometric group, CG- Control group

Summary

Both ST and PT have been reported to improve sprinting speed in the youth population across maturation. Based on previous studies that included young males, it is believed that ST is more useful in mid and post PHV boys whereas PT is more effective in pre PHV boys. However, limited studies have investigated the effects of ST and PT on sprinting speed in young females compared to their male counterparts. Most studies have investigated combined effects of ST and PT on sprinting speed in young females. To date, no study has compared ST and PT on sprinting speed in young females. Therefore, more research in this particular cohort is warranted.

Chapter 4: Intraday and inter-day reliability of sprinting kinetics in young female athletes measured using a radar gun.

Preface

The review of the literature informed that there is a paucity of research investigating sprinting kinetics and kinematics, and the effects of ST and PT on sprinting kinetics in young females. However, before any further investigation is conducted, it was important to establish between session and days reliability of sprinting kinetics using a piece of field-based equipment, the radar gun that can provide useful information with regards to sprinting kinetics in this population. Radar gun has been found to be reliable in informing specific sprinting kinetics in the adult population and elite young males. However, due to variability in force production in lesser trained young females with limited exposure to sprinting, it is important to first establish the reliability in this population. Therefore, chapter 4 measured the intraday and inter-day reliability of sprinting speed over 30 metres in young females.

Introduction

Speed is commonly measured using timing gates (Kawamori, Nosaka, & Newton, 2013). Timing gates can eliminate error and user bias and traditionally been regarded as the gold standard for timing sprint speeds (Mayhew et al., 2010). Previously, researchers have reported high reliability (CV < 5%) in measuring split times using the timing gates in the youth population (Sawczuk et al., 2018). However, while the reliability of photoelectric cell technology is sound (Cronin & Templeton, 2008; Duthie et al., 2006; Sawzuk et al., 2018), the technology provides little insight into the biomechanical factors that affect sprint performance (Simperingham, Cronin, & Ross, 2016). More specifically, timing gates provide no information about the biomechanical variables of a sprint (Simperingham et al., 2016). In contrast, radar gun technology provides a force and velocity profile, which can be useful to guide specific sprint training strategies (Samozino et al., 2012). Previous research has shown that vertical and horizontal GRFs influence top speed and acceleration, respectively (Weyland et al., 2000; Brughelli et al., 2011). Therefore, to optimise speed assessment, valid and reliable insight into both the kinematic and kinetic determinants of sprinting performance is important (Simperingham et al., 2016).

Recently, advanced diagnostic tools have been successfully used to inform sprint training (Simperingham et al., 2016). Radar systems such as ATS Stalker (ATS Stalker 2, Version 5.0.2.1, Applied Concepts Inc, Texas, USA) emit high-frequency waves, which bounce off the sprinting participant (Simperingham et al., 2016). Reflected radio wave signals are converted into a stream of digital data that, when processed with specific software, provide the forward running speed of the participant (Morin et al., 2006; Simperingham et al., 2016). The radar gun operates at a certain sampling frequency, providing a time series of horizontal velocity, force, power, and displacement (Bezodis, Salo, & Trewartha, 2012; Buchheit et al., 2014; Cross et al., 2015; Morin, Edouard, & Samozino, 2011; Morin et al., 2006).

The force-velocity relationship is useful when reporting on maximal sprinting speed as it describes the mechanical capabilities of the body (Simperingham et al., 2016). Using velocity measured by the radar gun, the relationship can be summarised by the following three variables: the theoretical maximal horizontal force at zero velocity (*Fo*), the theoretical maximal velocity at zero force (*Vo*) and the maximum power output (*Pmax*) (Rabita et al., 2015; Samozino et al., 2010). Therefore, a radar gun can be useful in providing more insights into the force and velocity profile of an athlete.

Using radar and/or laser technology, prior research has reported acceptable intraday reliability of acceleration and sprinting speed over a range of distances up to 100 m (CV ≤ 9.5%; systematic error ≤ 4.1%; ICC ≥ 0.84) and at least moderate inter-day (ICC ≥ 0.72; systematic error (bias) ≤ 6%) inter-day reliability (Debaere, Jonkers, & Delecluse, 2013; Delecluse et al., 2005; Di Prampero et al., 2005; Ferro, Villacieros, Pablo, & Graupera, 2014; Simperingham et al., 2016). Specifically, inter-day reliability of *Fo, Vo, and Pmax* has been reported for force-velocity relationship in sprinting (CV = 1.1-4%; standard error of measurement SEM = 1.4-5%) in high-level sprinters using the radar gun (Samozino et al., 2015). Reliability of *Fo, Vo***,** *Pmax* has also been established (ICC = 0.83-0.98, CV = 2.1-7.3%) using the radar gun in amateur club rugby union players (Simperingham et al., 2017). However, split times over the initial 10 m and some variables that included horizontal force component had only moderate reliability (ICC = 0.49-0.74). (Simperingham et al., 2017). This could be due to variability during the start of the sprint.

Limited studies have investigated the reliability of 30 m sprint performance and its determinants using radar technology in youth population (Buchheit et al., 2014). Previous studies that investigated reliability of sprinting kinetics using a radar gun included either highly trained (minimum 3 years) elite youth male athletes and semi-professional adult athletes (Buchheit et al., 2014; Simperingham et al., 2017). To the authors' knowledge, no prior research exists that investigates such data in lesser trained young female athletes. Due to the changes in growth, body size, muscle size, fibre composition, connective tissue stiffness and hormonal levels as discussed in Chapter 2, the kinetic factors associated with sprinting may vary in young females compared to their male counterparts (Malina et al., 2004; Radnor et al., 2018; Chidi-Ogbolu, & Baar, 2019). The force generating capacity in elite male youth and semi-professional adult athletes could be more consistent compared to their lesser trained female counterparts. In addition, variability in the initial part of the sprint due to inability to apply force in the right direction may also impact consistency due to lower training age and exposure to sprint training. Therefore, the purpose of this study was to determine the relative and absolute reliability of a radar gun to measure sprint speed and its kinetic determinants in young female athletes.

Methods

Participants

Twenty-nine young female athletes aged 13.70 $\pm$ 0.89 (height = 1.62 $\pm$ 0.06 m; weight = 51.70 $\pm$ 8.41 kg) from sports teams (hockey, football, netball, athletics and water polo) at a private girl's college were recruited for this study. All the twenty-nine athletes volunteered to participate in the intraday reliability analysis. Out of the 29 athletes, 14 of them volunteered for the inter-day reliability analysis. All participants were healthy, without any reported injuries in the last 3 months and had a training age of minimum 1 year in their respective sports. The study was approved by the Auckland University of Technology Ethics Committee.

Procedure

Participants attended two testing sessions separated by seven days for inter-day analysis and at least one session for intraday analysis along with a familiarisation session (no data recorded). Each testing session began with a standardised warm-up, including two 20 m multidirectional runs each (forward, backward, shuffle and crossover), dynamic stretching and three sub-maximal sprints at 50%, 75%, 90% effort. Participants performed the same warm up, observed by the researcher, on each testing day for the inter-day reliability. Following the warm-up, participants recruited for the intra-day reliability test performed two 30 m sprints over-ground at 100% effort, separated by 5 minutes of passive recovery (standing with very little movement). Similarly, participants recruited for the inter-day reliability test performed two 30 m sprints over-ground at 100% effort, separated by 5 minutes of passive recovery (standing with minimal movement) on two occasions separated by a week. Participants sprinted from a static split stance position with their leading foot immediately behind the start line. The first testing session involved familiarisation and no data were recorded. A radar gun (ATS Stalker 2, Version 5.0.2.1, Applied Concepts Inc, Texas, USA) with a sampling rate of 47 Hz, placed 5m directly behind the start line, was used to measure sprint speed. The operating range of the gun was set at 0 m/s (low-from zero acceleration starting position) to 14 m/s (high- typical top end speed that is not surpassed). The gun was set on a tripod set at 0.9 m above ground to approximately align with the centre of mass of the participants (Morin et al., 2006). The radar gun was triggered by the keyboard of the laptop attached to the gun before the start of every sprint and was stopped after each sprint was completed. No false start was allowed and participants were instructed to sprint maximally to a fixed marker 5 m past the 30 m mark (Simperingham et al., 2017). Standardized verbal instructions and encouragement were used in all testing sessions, which were performed at approximately the same time of the day (approximately midday) and week on an outdoor hockey turf court to control the testing conditions. Participants were required to abstain from any high-intensity training in the 24 hours before each testing session.

Horizontal velocity was measured continuously using the radar device connected to a laptop running Stalker ATS System software (Version 5.0.2.1, Applied Concepts

Inc, Texas, USA) (Simperingham et al., 2017). The raw data files were automatically processed using the digital filter "dig light". This function is available within the software and precisely removes noise frequencies while preserving data frequency being measured. The dig light filter applies minimal filtering and suitable for "clean" radar data and applies a fourth order (one round trip), Butterworth low-pass zero lag filter with a cut off frequency of 8 Hz. To improve consistency all trials were nominated to be acceleration runs hence forcing the start of the velocity-time curve through the zero point (Simperingham et al., 2017). The processed data were then imported into a custom-made Lab View (Version 13.0, National Instruments, Corporation, Texas, USA) to calculate all outcome variables (*Fo, Vo, Pmax, Vmax* and split times between 0 and 30 m) (Buchheit et al., 2014; Cross et al., 2015; Morin & Seve, 2011). The velocity-time curve [v(t)] for each sprint was calculated using the exponential function $v(t)= V_{max} \times (1 - e^{-t/\tau})$ (Al Haddad, Simpson, & Buchheit, 2015), horizontal acceleration was calculated from Newton's second law of motion $F_h(t) = [m \times a(t)] + F_{air}(t)$ (Arsac & Locatelli, 2002) and *Pmax* was calculated through the equation $P_{max} = (0.5 \times F_o) \times (0.5 \times V_o)$ (Bezodis et al., 2012). Data recorded for both the trials were used in the assessment of intra-day and the best trials on each for the inter-day reliability.

Statistical Analysis

The mean and standard deviation was calculated for *Vo, Fo, Pmax, Vmax* and 0-30 m split times (i.e., 0-10, 0-20, 0-30). 1) Intra-day and inter-day test-retest reliability was assessed by the change in mean to establish if average performance increased or decreased across sessions, 2) (ICC) for relative reliability using IBM SPSS, V.25 (SPSS Inc, Chicago, IL, USA), 3) CV for absolute reliability including 95% confidence intervals for each measurement variable (Hopkins, 2000), 4) the smallest worthwhile change (SWC) (Hopkins, 2004), and 5) Bias and limits of agreement (LOA) were analysed (Weir, 2005; Atkinson, & Nevill, 2000)**.** For the intraday analysis, CV, ICC, bias, and LOA values were calculated from the two sprints performed during one session, whereas for the inter-day analysis CV, ICC, bias and LOA values were calculated for day 1 versus day 2 (2,1) (Simperingham et al., 2017). The best trials from both the days were used for the inter-day reliability analysis.

The ICC results were interpreted as follows: 0.20-0.49 = low, 0.50-0.74 = moderate, 0.75-0.89 = high, 0.90-0.98 = very high and 0.99 = extremely high (Hopkins et al., 2009). A CV of < 10% was considered small (Bradshaw et al., 2010). The reliability of each measure was interpreted as acceptable for an ICC ≥ 0.75 and a CV ≤ 10%, moderate when ICC < 0.75 or CV >10% (Simperingham et al., 2017).

Results

Intraday reliability

The mean, standard deviation (average scores from both trials), bias, LOA and SWC were calculated using both the sprints performed on the first day of testing for intraday reliability analysis. (Table 4.1). The typical error expressed as CV was small (<10%) for all variables but moderate for *Fo* (12.70%). The ICC values were acceptable across variables (0.80). The smallest worthwhile change was lower than the CV for all radar-derived variables for intraday reliability analysis. In addition, the bias between trials ranged from 0.65 to 1.65 % across variables as shown in table 4.1

Table 4.1: Intraday reliability of sprinting kinetics

Variable	Mean ± SD	CV%	ICC	SWC	Bias	LOA 95% CI (LOWER)	LOA 95% CI (UPPER)
Vo (m/s)	7.25 ± 0.67	4.10 (3.20-5.60)	0.80 (0.62-0.90)	0.13 (1.79%)	-0.12 (1.65%)	-0.94	0.69
***Fo* (N)**	233.02 ± 66.77	12.70 (10.00-17.60)	0.89 (0.77-0.94)	13.40 (5.75%)	-2.21 (0.95%)	-64.9	60.5
***Pmax* (W)**	411.68 ± 135.60	9.70 (7.60-13.40)	0.95 (0.95-0.99)	27.12 (6.38%)	-5.32 (1.29%)	-89.5	78.9
***Vmax* (m/s)**	6.92 ± 0.57	3.20 (2.60-4.40)	0.85 (0.70-0.93)	0.11 (1.59%)	-0.08 (1.15%)	-0.69	0.53
10 m (s)	2.81 ± 0.34	4.20 (3.30-5.70)	0.85 (0.71-0.93)	0.07 (2.49%)	0.03 (1.10%)	-0.33	0.38
20 m (s)	4.39 ± 0.40	3.00 (2.30-4.00)	0.88 (0.76-0.94)	0.08 (1.82%)	0.03 (0.66%)	-0.36	0.41
30 m (s)	5.90 ± 0.47	2.40 (1.90-3.30)	0.84 (0.68-0.92)	0.09 (1.52%)	0.04 (0.65%)	-0.38	0.45

Vo- Theoretical velocity; *Fo*- Force; *Pmax*- Power max; *Vmax*- Velocity max; LOA- Limits of Agreement; CI- Confidence limit

*CVs and ICCs are presented as mean together with 95% confidence limits. Smallest worthwhile change (SWC) is presented both as units (left hand side) and % of the mean (right hand side). Bias is also presented both as units (top) and % (bottom).

Inter-day reliability

The mean, standard deviation (average scores from best trials on both days), bias, LOA and SWC were calculated using the best sprints from each day for the inter-day reliability analysis. The typical error expressed as the CV was relatively small (<10%) for all variables but moderate for *Fo* (11.20%). The ICC values were acceptable (0.79) for all variables except *Vo* (ICC = 0.74) (Table 4.2). The smallest worthwhile change was lower than CV for *Vo, Fo, and Vmax* but greater for *Pmax*, 10, and 30 m split times. In addition, the bias between days ranged from 0.25 to 2.20% across variables shown in table 4.2.

Table 4.2: Inter-day reliability of sprinting kinetics

Variables	Mean ± SD	CV%	ICC	SWC	Bias	LOA 95% CI (LOWER)	LOA 95% CI (UPPER)
Vo (m/s)	Day 1- 7.31 ± 0.50 Day 2- 7.22 ± 0.49	3.40 (2.50-5.60)	0.74 (0.37-0.91)	Day 1-0.10 (1.36%) Day 2-0.10 (1.38%)	-0.09 (1.18%)	-0.78	0.61
***Fo* (N)**	Day 1- 253.07 ± 78.65 Day 2- 250.64 ± 86.31	11.20 (8.00-18.70)	0.95 (0.84-0.98)	Day 1-15.73 (6.2%) Day 2-17.26 (6.89%)	-2.43 (0.96%)	-55.0	50.2
***Pmax* (W)**	Day 1- 459.36 ± 148.59 Day 2- 451.43 ± 146.28	5.70 (4.10-9.40)	0.98 (0.98-0.99)	Day 1-29.72 (6.47%) Day 2-29.23 (6.47%)	-7.93 (1.81%)	-65.4	49.5
***Vmax* (m/s)**	Day 1- 7.00 ± 0.43 Day 2- 6.85 ± 0.41	2.80 (2.00-4.60)	0.79 (0.46- 0.93)	Day 1-0.09 (1.29%) Day 2-0.08 (1.17%)	-0.15 (2.20%)	-1.21	0.37
10m(s)	Day 1- 2.80 ± 0.37 Day 2- 2.79 ± 0.35	2.10 (1.50-3.40)	0.97 (0.92-0.99)	Day 1-0.08 (2.86%) Day 2-0.07 (2.5%)	-0.00 (0.25 %)	-0.17	0.16
20m(s)	Day 1- 4.36 ± 0.44 Day 2- 4.38 ± 0.45	2.30 (1.70-3.70)	0.94 (0.83-0.98)	Day 1-0.09 (2.06 %) Day 2-0.09 (2.05%)	0.02 (0.46%)	-0.28	0.32
30m(s)	Day 1- 5.85 ± 0.53 Day 2- 5.90 ± 0.54	1.70 (1.20-2.70)	0.92 (0.77- 0.97)	Day 1-0.11 (1.88%) Day 2-0.11 (1.86%)	0.05 (0.85%)	-0.22	0.32

Vo- Theoretical velocity; *Fo*- Force; *Pmax*- Power max; *Vmax*- Velocity max; LOA- Limits of Agreement; CI- Confidence limit

* CVs and ICCs are presented as mean together with 95% confidence limits. Smallest worthwhile change (SWC) is presented both as units (top) and % of the mean (bottom). Bias is also presented both as units (top) and % (bottom).

Discussion

This is the first study to investigate the reliability of radar-derived kinetic variables and 0-30 m split times in young female athletes. Given the importance of kinetics in sprinting speed, it was crucial to establish the reliability using a radar gun to derive sprinting kinetics in this cohort**.** The findings showed acceptable intra-day and inter-day reliability for *Fo, Pmax, Vmax* and split times. These results concur with studies by Buchheit et al. (2014) and Simperingham et al. (2017), which reported acceptable intra-day (ICC=0.87-0.97; CV= 1.50-8.90%) and inter-day (ICC = 0.75 and CV= 10%) reliability for laser and radar-derived values of kinetic and kinematic variables in highly trained young male soccer players and adult recreational athletes, respectively.

The inter-day reliability for *Vo* in this study was moderate (ICC=0.74). In comparison, Simperingham et al. (2017) reported high inter-day reliability (ICC=0.83-0.93) for the same variable. This difference may be due to increased variability during the start and motivational levels among the participants in the present study (Simperingham et al., 2017; Steenman et al., 2016). Specifically, horizontal velocity during sprinting can be impacted by variability during the first several steps, thus interfering with the reliability of the measure (Simperingham et al., 2017). Bezodis et al. (2012) also reported an unacceptable level of error over the first 5 m compared to distances at 10, 30 and 50 m sprints, when measured by laser technology (LOA =0.41$\pm$ 0.18m/s at 1m, and 0.13 $\pm$ 0.21 m/s at 5 m). In addition, Bezodis et al. (2012) reported greater bias at 1m than 30 m. Even though this study did not measure speed <10 m distance, the bias was similar at 30 m compared to Bezodis et al. (2012) (0.05 m/s vs. 0.06 m/s). The authors attributed the increased variability at the start of the sprint mainly to an upright posture, an upright posture may have negatively impacted consistency in tracking the lumbar region (laser tracking reference point) as the sprinter rose off the blocks (Bezodis et al., 2012). Accordingly, the use of static starts may cause greater variability in force and velocity measures during the first few steps of a sprint (Buchheit et al., 2014; Simperingham et al., 2017).

Furthermore, muscle power and sprinting are dependent on individual motivational levels (Steenman et al., 2016), which could have also impacted the reliability of *Vo* between days in this study. In addition, variability can also increase if participants do not run directly away from the radar gun at the start of the sprint. Therefore, using a rolling start and providing instruction to run directly in front of the radar gun to assess horizontal velocity during sprinting may help to reduce variability as force is produced more consistently (Simperingham et al., 2017). Along with rolling starts incorporation of immediate visual feedback tools such as timing gates can increase activity awareness thus increasing motivational levels (Bice, Ball, & McClaran, 2015).

This study found acceptable reliability (ICC = 0.89 and 0.95) for *Fo* unlike Buccheit et al. (2014) and Simperingham et al. (2017) studies that reported only moderate reliability (ICC= 0.64) and (ICC = 0.49-0.75) respectively. However, CVs for *Fo* was relatively higher compared to other variables in this study (>10%). This may be because participants in this study were not consistent in applying force at the start and rose off early. The initial acceleration is dependent on the relative force output as $F=m \times a$ (Force = mass times acceleration) based on Newton's second law of motion. Any variability in force output will also influence acceleration hence affecting split times particularly ≤10 m to overcome inertia as reported in Simperingham et al. (2017) and Ferro et al. (2014) studies (ICC= 0.49-0.74). Therefore, this study did not investigate the reliability of 2 and 5 m split times but reported a high ICC for 10, 20 and 30 m split times between days as shown in Tables 4.1 and 4.2.

This study used an automated editing technique, along with the purposed built analysis software to process the force-velocity data. This was in contrast with Simperingham et al. (2017), who used manual editing. Automated editing may have increased reliability due to greater consistency in analysing the data. However, similar to how Simperingham et al. (2017) analysed data, this study forced the start of the velocity-time curve through the time-point zero. Therefore, the start of the sprint was standardised for all trials eliminating any noise prior to the sprint.

In addition, the SWC for all intra-day analysis variables were found to be lower in the present study compared to the CV but greater for *Pmax*, 10 and 30 m split times for the inter-day analysis consistent with the Simperingham et al., 2017 study. Ideally, the typical error (expressed as CV) should be lower than the smallest worthwhile change (Hopkins, 2004). A lower CV for a test with regards to SWC suggests less random noise (variation). Therefore, reducing the variation between tests increases the likelihood of identifying a real change in performance (Duthie et al., 2006).

Conclusion

Given the acceptable intra and inter-day reliability of *Fo, Vmax, Pmax*, and 30 m split times shown in this study, radar technology, and force-velocity profiling can be confidently used in monitoring changes in the mechanical capabilities of young female athletes, including horizontal force, power production and sprints as short as 10 metres. Further research is warranted to investigate the reliability of a radar gun using a ‘rolling start’, incorporation of immediate visual feedback tool such as timing gates, and for distances shorter than 10 m in this population.

Chapter 5: Kinetics and kinematics of sprinting speed in mid and post peak height velocity female athletes

Preface

Chapter 4 investigated the intraday and inter-day reliability of the radar gun for specific kinetic variables such as *Fo, Pmax, Vo, Vmax*, 10, 20, and 30 m split times, and reported acceptable reliability across all variables. Now that reliability of sprinting kinetics was established using the radar gun, the following chapters 4, 5 and 6 incorporated the radar gun to measure sprinting kinetics. Limited studies have investigated sprinting kinetics and kinematics in the youth population and no study has specifically looked into specific kinetic and kinematic measures such as *Fo, Vo, Pmax, Vmax,* step length, frequency, contact and flight time in young females controlling for maturity. Therefore, Chapter 4 investigated the kinetics and kinematics of sprinting speed and their relationship on maximal velocity over 15 and 30 m in mid and post PHV girls.

Introduction

Running velocity in youth is determined by several factors such as anthropometry (measurements and proportions of the body), kinetics (horizontal and vertical forces) and kinematics (step length, frequency, contact and flight time) (Rumpf et al., 2015; Meyers et al., 2015; Meyers et al., 2017b). Most studies that have investigated kinetic (horizontal and vertical forces) and kinematic (step length, step frequency, contact time, and flight time) variables of sprinting speed have been conducted in adult populations (Simperingham et al., 2017; Brughelli, Cronin, & Chaouachi, 2011; Nilsson & Thorstensson, 1989; Nummela, Keranen, & Mikkelsson, 2007) with limited studies on youth (Schepens, Willems, Cavagna, 1998; Rumpf, et al., 2015; Meyers et al., 2015; Meyers et al., 2017a; Nagahara et al., 2019). Due to growth, maturity and changes in anthropometry, the interaction between kinetic and kinematic variables can play a significant role in sprinting speed in youth across maturation (Rumpf et al., 2015).

It has been reported that sprinting speed in boys and girls tends to develop in a non-linear fashion throughout childhood and adolescence (Viru et al., 1999) with accelerated development of sprint performance during both preadolescent and adolescent periods (Meyers et al., 2015; Viru et al.,1999). Furthermore, according to the YPD Model speed training can be broken down into three different stages (prior to late adolescence stage): early childhood (age 0-7), prepubertal (age 7-12), circumpubertal (age 11-15 males, age 12-15 females) and late adolescence (age 16+ males, age 15+ females) (Lloyd & Oliver, 2012; Oliver, Lloyd & Rumpf, 2013). Even if the chronological reference regarding speed development windows can provide flexibility in training, it is important to consider PHV as it coincides with crucial development of speed during growth spurts (Philippaerts et al., 2006). Therefore, natural development of speed may be maturity dependent and requires further investigation (Meyers et al., 2015; Rumpf et al., 2015).

Limited studies have investigated the role of maturity in the kinetic and kinematic variables of sprinting speed among youth. Rumpf et al. (2015) found significant differences in kinetic (horizontal and vertical force) and kinematic variables (step length and frequency) in young male athletes across maturation particularly between pre and mid PHV athletes (8-78%, $p<0.05$). Similarly, Meyers et al. (2015) reported significant differences in stride length between pre and mid PHV boys but not between mid and post PHV boys ($p<0.05$). Meyers et al. (2016) also reported significantly greater increases in speed (10.4% vs 5.6%), relative vertical stiffness (12.1% v 5.6%) in pre to post boys compared to pre PHV boys ($p<0.05$). In addition, stride frequency and contact time seem to be significantly different between early pre PHV and pre PHV boys but not mid and post PHV boys ($p<0.05$) (Meyers et al., 2015; Meyers et al., 2016). This could be because boys who are early pre PHV may lack motor coordination and strength to effectively orientate, stabilise and apply force through their limbs compared to mid and post PHV boys (Meyers et al., 2015).

Furthermore, it is hypothesised that due to rise of testosterone and growth hormones during puberty (Ramos et al., 1998; Forbes et al., 2009), improvements in strength and power output may affect force production (Armstrong et al., 2000; Forbes et al., 2009). Hence, kinetics and kinematics of running may differ in participants of varying maturity status. However, the secondary sex characteristics caused by an increased secretion of growth hormones during puberty, can increase fat mass in girls compared to boys as discussed in Chapter 2 (Malina et al., 2004). This can inhibit force production and negatively affect sprinting speed. In addition, studies have reported a negative relationship between body fat mass and kinematic variables of sprinting speed such as step length, and step frequency in post and pre PHV boys respectively (Meyers et al., 2017a). Therefore, it is important to investigate sprinting kinetics and kinematics across maturation in girls.

It appears that limited studies have investigated kinetics and kinematics of sprinting speed in young females across age groups (Nagahara et al., 2019; Vanderka & Kampmiller, 2012). Furthermore, previous studies did not include maturity offset and divided girls based on their chronological age (Nagahara et al., 2019; Vanderka & Kampmiller, 2012). Due to the disparity in variables associated with sprinting speed across age groups, it is important to consider maturity offset to determine the changes in kinetic and kinematic variables of sprinting speed in young females. Nagahara et al. (2019) reported significant changes in sprinting speed between younger (<12.7 years) and older girls (>12.7 years). The older girls in this study were significantly quicker than the younger girls for 25 m and 50 m sprints ($p<0.05$). However, the step length rate over maximal sprint and propulsive forces during acceleration were significantly greater 0.08 m/y and 0.024 Ns/ in the younger girls compared to 0.01 m/y and -0.010 Ns/y in the older girls. Similarly, Vanderka and Kampmiller (2012) reported a stagnation in sprinting speed and step length beyond (average age of 13.5 years) in girls compared to boys. The differences in sprinting kinetics and kinematics in the previous studies may be due to the greater growth rates in the younger girls and greater fat mass with maturation in older girls (Nagahara et al., 2019).

In addition, a recent study that investigated GRFs in sprinting in both boys and girls (untrained) reported that the increase in maximal velocities in pre PHV girls (2.5-1.5 years before PHV) compared to pre PHV boys (1.5-0.5 years from PHV) were not attributed to increase in GRFs but rather due to longer ground contact time (ES: ± 90% CI = 1.00 ± 0.78) (Coyler et al., 2020). However, the study included non-athletic pre PHV girls that may not provide relevant insights into sprinting kinetics and kinematics across maturation, particularly in mid and post PHV female athletes.

Therefore, the purpose of this study was to determine the kinetics and kinematics of sprinting speed in mid and post PHV female athletes and investigate their relationship with maximal velocity.

Methods

Participants

Thirty- two female athletes (11 mid PHV and 21 post PHV) from sports teams (hockey, football, netball and water polo) with a minimum training age of 1 year in their respective sports at a private girl's college in New Zealand volunteered for this study. All participants were healthy and without any reported injuries in the last 3 months. The study was approved by the Auckland University of Technology Ethics Committee. All participants and their legal guardians were informed of the risks and benefits of participation and both legal guardians and participants provided written consent and assent to participate in this study. The participants' characteristics are provided in table 5.1.

Table 5.1: Characteristics (Mean± SD) of participants across maturity groups

Groups	Age (years)	Maturity Offset (years from PHV)	Height (m)	Leg length(cm)	Body mass (kg)
Mid- PHV	12.70 ± 0.56	0.58 ± 0.35	1.56 ± 0.07	85.14 ± 5.02	42.05 ± 6.75
Post- PHV	13.53 ± 0.91	1.82 ± 0.50	1.66 ± 0.04	91.40 ±3.36	54.79 ± 7.64

*Significant difference ($p<0.05$) in leg length, height and body mass

Anthropometric measurements and date of birth were taken before familiarisation, including height (m), sitting height (m), leg length (cm) and weight (kg). Maturity status of the participants was calculated using the Mirwald and colleagues' equation (2002). This method is considered non-invasive and predicts years from PHV as a measure of maturity offset using anthropometric variables. Participants are generally classified into three groups as follows pre PHV velocity (-3 years to -1 years from PHV), mid PHV (-1 to +1 years from PHV), and post PHV (+1 to +3 years from PHV) (Rumpf et al., 2012). The standard error of this equation has been reported to be

0.57 years in girls. (Koziel & Malina, 2018). The equation for maturity offset for girls was:

Maturity Offset for girls *= -9.376 + 0.0001882·Leg Length and Sitting Height interaction + 0.0022·Age and Leg Length interaction + 0.005841·Age and Sitting Height interaction - 0.002658·Age and Weight interaction + 0.07693·Weight by Height ratio·100*

Procedures

Participants were required to attend three sessions. First, a familiarisation session was conducted 2 days before any data were collected, consisting of various intensity sprints. Then, participants attended a second session during which their sprinting speed over a distance of 30 m was assessed using a radar gun (Version 5.0.2.1, Applied Concepts, Inc, Texas, USA) to determine kinetic variables including *Fo*, *Vo*, and *Pmax*. Participants sprinted from a static split stance position with their leading foot immediately behind the start line. A radar gun (Version 5.0.2.1, Applied Concepts, Inc, Texas, USA) with a sampling rate of 47 Hz, placed 5 m directly behind the start line, was used to measure sprinting speed. The operating range of the gun was set at 0 m/s (low-from zero acceleration starting position) to 14 m/s (high- typical top end speed that is not surpassed). The gun was set on a tripod set at 0.9 m above ground to approximately align with the centre of mass of the participants (Morin et al., 2006). No false start was allowed and participants were instructed to sprint maximally to a fixed marker 5 m past the 30 m mark (Simperingham et al., 2017). Participants performed two maximal sprints separated by 5 min of passive rest and the best of the two based on all dependent variables (*Fo, Pmax, Vo)* were taken for analysis.

Horizontal velocity was measured continuously using the radar device connected to a laptop running Stalker ATS System software (Version 5.0.2.1, Applied Concepts Inc, Texas, USA) (Simperingham et al., 2017). The raw data files were automatically processed using the digital filter “dig light”. This function is available within the software and precisely removes noise frequencies while preserving data frequency being measured. The dig light filter applies minimal filtering and suitable for “clean” radar data and applies a fourth order (one round trip), Butterworth low-pass zero lag filter with a cut off frequency of 8 Hz. To improve consistency all trials were nominated to be acceleration runs hence forcing the start of the velocity-time curve through the zero point (Simperingham et al., 2017). The processed data were then imported into a custom-made Lab View (Version 13.0, National Instruments, Corporation, Texas, USA) to calculate all outcome variables (*Fo, Vo, Pmax, Vmax* and split times between 0 and 30 m) (Buchheit et al., 2014; Cross et al., 2015; Morin & Seve, 2011). The velocity-time curve [v(t)] for each sprint was calculated using the exponential function $v(t) = V_{max} \times (1 - e^{-t/\tau})$ (Al Haddad, Simpson, & Buchheit, 2015), horizontal acceleration was calculated from Newton's second law of motion $F_h(t) = [m \times a(t)] + F_{air}(t)$ (Arsac & Locatelli, 2002) and *Pmax* was calculated through the equation *Pmax* = (0.5× *Fo*) × (0.5× *Vo*) (Bezodis et al., 2012). Data recorded for both the trials were used in the assessment of intra-day and the best trials on each for the inter-day reliability. A moderate to strong ICC = 0.74-0.98 with a CV ranging from 1.70-12.70% across all kinetic variables (*Fo, Vo, Vmax, Pmax*, 10, 20, and 30 m split times) were reported for both intraday and inter-day reliability in this population (see Chapter 4).

The third session involved participants sprinting over a distance of 15 m to assess kinematic variables including step length, step frequency, flight time, contact time and velocity max using the Optojump Next System (Microgate, Bolzano, Italy) positioned at floor level. No false start was allowed and participants were instructed to sprint maximally to a fixed marker 5 m past the 15 m mark (Meyers et al., 2015). Data for all the sprinting kinematic characteristics were collected using a Windows laptop via Optojump software (Microgate, Italy) and later exported to Microsoft Excel for processing (Meyers et al., 2015a). The reliability between trials for all kinematic variables in this study were high with ICC ranging from 0.81-0.94 and CV ranging from 1.7-5.7%. Previous researchers have also reported strong ICC = 0.87-0.98 and CV = 0.6-5.5% in measuring stride characteristics in the adult population using the Optojump (Oliver & Stembridge, 2011). Kinematic variables (step length, step frequency, contact time, and maximal velocity for 15 m) were derived from the Optical measurement system and kinetic variables (*Fo, Pmax* and *Vo* over 30 m) were derived using the radar gun were defined as follows (Meyers et al., 2015; Simperingham et al., 2017):

Step length (cm): distance covered during the flight phase
Normalised step length (cm): step length divided by leg length
Step frequency (Hz): 1/contact time + aerial time of a step length
Contact time (s): the amount of time (s) the participant spends during the stance phase of the sprint where the foot is in contact with the floor
Flight time (s): the amount of time (s) between foot contacts, where the participant is not in contact with the floor
Pmax (W): Peak horizontal forces × velocity
Vmax(m/s): Maximum speed attained for the distance 15 m by the participant
Vo (m/s): theoretical velocity max attained by the participant over the distance of 30 m
Fo (N): Horizontal forces associated with sprinting over the distance of 30 m

All the sessions began with a standardised warm-up, including 20 m multi-directional runs (forward, backward, shuffle and crossover), dynamic stretching and a series of sub-maximal sprints (50%, 75%, 90% effort). Five minutes and 2.5 minutes of passive rest were given between 30 and 15 m sprints, respectively.

Statistical Analysis

Means and the standard deviation (SD) were used for all dependent variables of interest as measures of centrality and spread of data using SPSS V.25 (SPSS Inc, Chicago, IL, USA). Tests of model assumptions (conditional SD, mean and distribution) were carried out. Univariate regressions were conducted to a) to detect changes across variables between both groups and b) identify which kinematic and kinetic factors were important in predicting maximum velocity when maturity offset was controlled. Regression analysis was also used to determine whether any outliers were present and normal distribution of data. An alpha level of 0.05 was used for all statistical tests.

Results

There was a significant difference between the groups with regards to height, bodyweight and leg length (Table 5.1). Mean values of the variables of interest and their percentage change are reported in table 5.2.

Table 5.2: Means, standard deviation and differences for all variables between maturity groups

Variables	MID PHV	POST PHV	Min (95% CI)	Max (95% CI)	% Difference
Contact time (s)	0.17 ± 0.02	0.17 ± 0.02	-0.01	0.02	2.83
Flight time (s)	0.10 ± 0.01	0.10 ± 0.01	-0.01	0.01	2.59
Step length (cm)	131.22 ± 9.43	141.66 ± 10.21	2.87	18.01	7.95*
Step frequency (Hz)	3.78 ± 0.26	3.68 ± 0.27	-0.31	0.10	-2.65
Normalized step length (Step length/leg length) (m/m)	1.54 ± 0.10	1.55 ± 0.12	-0.08	0.09	0.65
15 m *Vmax* (m/s)	5.20 ± 0.33	5.47 ± 0.25	0.06	0.49	5.19*
30 m *Vo* (m/s)	6.73 ± 0.60	7.40 ± 0.56	0.22	1.11	9.96*
***Fo* (N)**	201.24 ± 40.99	302.64 ± 60.53	59.36	143.44	50.39*
***Pmax* (W)**	336.91 ± 63.3	531.97 ± 128.72	110.48	279.64	57.90*

*****Significantly different between groups *p<0.05, Vo- theoretical velocity, Fo-* Force, *Pmax-* Power max, CI- Confidence intervals

In terms of kinematic variables, maximum velocity for the 15 m (5.19%) and step length (7.95%) were significantly higher ($p<0.05$) in post PHV girls (Table 5.2). However, when step length was divided by leg length there was no difference between the groups. Furthermore, there were no significant differences between the groups with regards to contact time and flight time. However, mid PHV girls had a marginally (non-significant) higher step frequency compared to post PHV girls. With regards to kinetic variables, it was found that *Vo* over 30 m (10%), *Fo* (50.39%) and *Pmax* (57.90%) were significantly higher in post PHV girls compared to mid PHV girls, as shown in table 5.2.

When maturity offset was controlled, regression analysis reported the predictors of velocity over 15 m were contact time, *Pmax*, step frequency, and step length. Whereas the predictors of velocity over 30 m were contact time, leg length and *Pmax*. In addition, out of all the variables, contact time and *Pmax* predicted maximal velocity for both 15 and 30 m sprints. However, contact time was the best predictor of sprint velocity for both 15 and 30 m sprints, followed by step frequency for 15 m and leg length for 30 m (Table 5.3). Moreover, *Pmax* and step length were not the strongest predictors with regards to magnitude but the standard error was comparatively lower (≤ 0.005) across variables (Table 5.3). Interpretation of the regression analysis is provided in Table 5.3 for each variable. Regression models of contact time and power max and their association with 30 m maximal velocity are shown in Figure 5.1 and 5.2.

Table 5.3: Predictor variables for velocity (15 and 30 m) when maturity was controlled

Variables	B	SE	T	P	Min (95% CI)	Max (95% CI)
CT (15 m)	-7.001	2.633	-2.662	0.0125	-12.395	-1.624
CT (30 m)	-11.416	5.784	-1.974	0.058	-23.245	0.413
***Pmax* (15 m)**	0.001	0.000	3.085	0.004	0.000	0.002
***Pmax* (30m)**	0.003	0.001	2.817	0.009	0.001	0.005
SF (15 m)	0.379	0.183	2.074	0.047	0.005	0.753
LL (30 m)	0.050	0.028	1.810	0.081	-0.007	0.107
SL (15 m)	0.010	0.005	2.077	0.047	0.000	0.020

*****CT- Contact time, *Pmax*- power max, SF- step frequency, LL- leg length, SL- step length, B-beta, SE- standard error, CI- confidence intervals

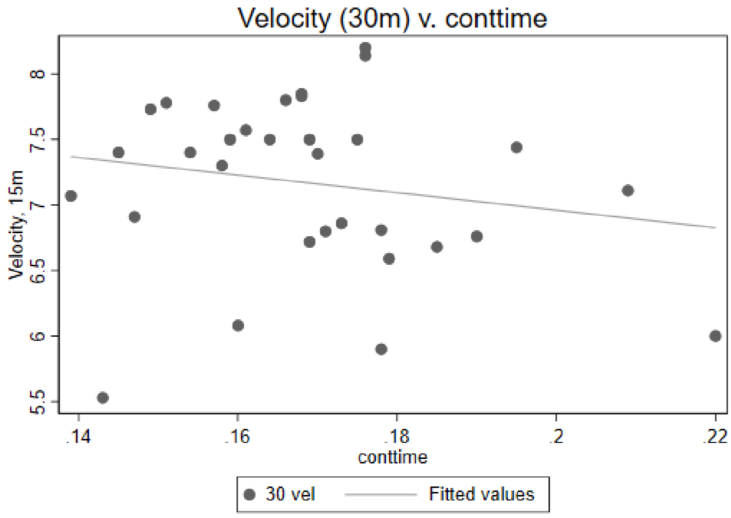

Figure 5.1 Regression model: Maximal velocity and Contact time

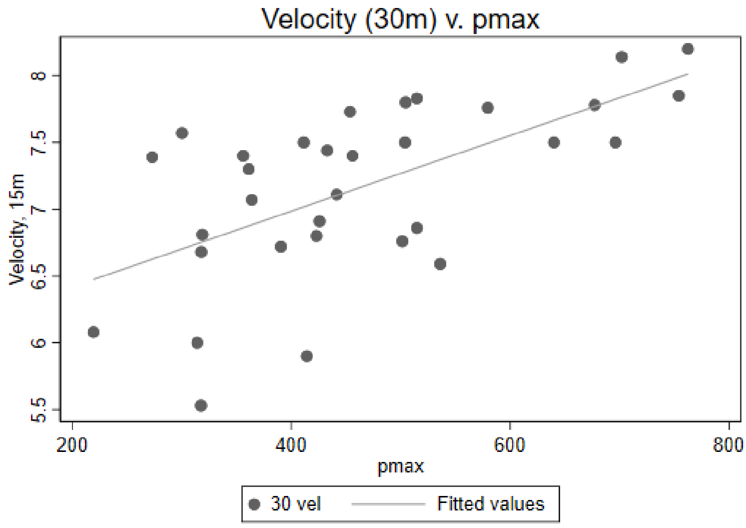

Figure 5.2: Regression model: Maximal velocity and Pmax

Discussion

The primary purpose of this study was to determine if the kinematics and kinetics associated with maximum sprinting velocity differ in female youth across maturation. Furthermore, it was also crucial to investigate if the kinematic and kinetic variables such as step length, step frequency, flight time, contact time, horizontal force and *Pmax* can predict maximal sprinting velocity across maturation in this cohort. The differences in kinetic and kinematic variables associated with maximal sprinting velocity can provide practical insights to coaches working with young female athletes. This study supports previous research that reported an increase in maximal velocity (15 m and 30 m) with maturation in youth populations ($p<0.05$) (Schepens, Willems, & Cavagna, 1998; Rumpf et al., 2015; Meyers et al., 2015; Meyers et al., 2016; Nagahara et al., 2019). This study also found that not all kinematic and kinetic variables measured were strong predictors of maximal velocity when maturity was controlled in this population.

With regard to kinematic variables, step length increased with maturity ($p<0.05$). However, when step length was divided by leg length (normalised step length) there was no difference between the groups. Rumpf et al. (2015) also found no significant difference in normalised step length between mid and post PHV boys. Similar to previous research (Rumpf et al., 2015; Meyers et al., 2015) this study did not find significant differences in contact time, flight time and step frequency between mid and post PHV groups. A possible explanation for this finding could be that contact time, flight time and step frequency tend to stabilise during mid and post PHV phases as greater changes tend to happen during the transition from pre to mid PHV phase (Meyers et al., 2015; Meyers et al., 2016; Rumpf et al., 2015). Therefore, maturity related improvements in strength and power output may enhance improvement in technical efficiency and force application, resulting in improved speed in post PHV females (Forbes et al., 2009; Ramos et al.,1998; Meyers et al., 2015).

The relative horizontal force (*Fo)* output over 30 m sprint was significantly different between mid and post PHV groups, with an average change of >50% (Table 5.2). This finding contrasts with those of Rumpf et al. (2015) study, which did not show significant differences between mid and post PHV boys in horizontal force but showed significant differences in vertical force ($p<0.05$). Therefore, suggesting that changes in horizontal forces between mid and post PHV groups might be greater in over ground sprinting as opposed to non-motorised treadmill.

Similar to Rumpf et al. (2015), power output for the 30m sprint was significantly different between mid PHV (337 W) and post PHV (532 W) participants in the present study. Since power was calculated as horizontal force multiplied by velocity, and a significant difference in horizontal force existed between groups, it would appear that horizontal force can significantly influence *Pmax* (Rumpf et al., 2015). However, the values in this study were modest compared to the Rumpf et al. (2015) study. This may be due to the differences in anthropometry, girls in this study had a lower body mass and height compared to the boys in Rumpf et al. (2015) study. Natural growth along with higher androgen levels with a greater anabolic effect in mid and post PHV boys could have played a role in greater maximal power compared to the girls in this study (Malina et al., 2004; Viru et al., 1999).

In agreement with previous research (Rumpf et al., 2015; Meyers et al., 2015), this study found step length to be a predictor of maximal velocity over 15 m. When maturity offset was controlled, for every cm increase in step length there was an increase of 0.010 m/s in maximal velocity. This could be attributed to leg length since there was an increase of 0.050 m/s in velocity with every cm increase in leg length over the distance of 30 m. This finding suggests that step length and leg length can influence maximal velocity over both 15 and 30 m respectively. Therefore, measuring step length and leg length can be crucial in investigating sprinting kinematics and maximal velocity in mid and post PHV girls.

In contrast to previous research (Rumpf et al., 2015; Meyers et al., 2015), this study showed step frequency as one of the predictors of maximal velocity over 15 m but not for 30 m. The maximal velocity in this study increased by 0.379 m/s with every Hz increase in step frequency. Previous study found step frequency to be a better predictor of maximal velocity in pre PHV boys compared to post PHV boys over 30 m (accounting for 58% variances in speed) (Meyers et al., 2017a). This could be due to the fact that this study investigated the relationship between step frequency and maximal velocity over the first 15 m unlike previous studies in boys (Rumpf et al., 2015; Meyers et al., 2015; Meyers et al, 2017a). It has been reported in male sprinters previously that step frequency is crucial in the initial phase of acceleration (Nagahara et al., 2014). Therefore, increasing step frequency in the initial phase of acceleration may be useful in improving maximal velocity in mid and post PHV girls.

Out of all the kinematic variables, contact time was found to be the best predictor of maximal velocity based on the model. Maximal velocity over 15 and 30 m decreased by -7.001 m/s and -11.416 m/s, respectively, with every second increase in contact time. If this model is applied contextually, then a 10% increase in mean contact time across mid and post PHV groups (0.17s) reported in this study will decrease maximal velocity by 0.12 m/s (2.23%) for 15 m and 0.19 m/s (2.69 %) for 30 m respectively based on the mean value of maximal velocity across both the groups. Previous research has also reported contact time to be a strong predictor of sprinting speed (R^2 = 0.70) in mid PHV boys (Rumpf et al., 2015). Therefore, reducing contact time in young females and males can be useful in improving maximal sprinting velocity.

With regards to kinetic variables, *Pmax* predicted velocity in this study across 15 m and 30 m distances when maturity offset was controlled. The velocity for 15 and 30 m distances increased by 0.001m/s and 0.003m/s respectively with every watt increase in power. Similar to the contact time, when this model is applied contextually then a 10% increase in power (43.44 W) based on the mean score (434.44W) for mid and post PHV groups will increase maximal velocity by 0.04 m/s (0.82%) for 15 m and 0.13 m/s (1.84%) for 30 m respectively. This finding was consistent with previous research that reported power to be a strong predictor of maximal velocity in post PHV boys with R^2 value of 0.35 (Rumpf et al., 2015). However, Rumpf et al. (2015) reported a greater R^2 = 0.76 when maturity groups were combined. This could be due to the fact that, unlike the present study, the authors included pre PHV boys in the combined regression modelling (Rumpf et al., 2015). Power related factors can influence sprinting velocity to a greater extent in pre PHV children due to the heightened nervous system in this phase of growth (Myer et al., 2013). Therefore, suggesting that *Pmax* may be a better predictor of maximal velocity in pre PHV compared to mid and post PHV boys and girls.

This present study revealed that *Fo* was not a strong predictor of maximal velocity even a significant difference between mid and post PHV girls existed ($p<0.05$). In contrast, Rumpf et al. (2015) reported horizontal force to be a strong predictor of maximal velocity in post PHV boys ($R^2 = 0.99$). A possible explanation could be that due to the differences in hormonal levels (testosterone vs. oestrogen) between genders, the force generating capacity in girls could be limited compared to their male counterparts (Malina et al., 2004). In a recent study, Coyler et al. (2020) also reported that the maximal velocity was not influenced by the force generating capacity in pre PHV girls compared to their male counterparts. In addition, the participants in this study were not trained sprinters and might have lacked the ability to apply force at the start (due to increased lean angle of the body) unlike trained young male soccer players sprinting on a non-motorised treadmill in Rumpf et al. (2015) study. Therefore, *Fo* was not found to be a strong predictor of maximal velocity in this study.

Conclusion

This study showed that maximum sprinting velocity for 15 and 30 m increased across maturity groups. Of all the kinematic variables, step length was found to be significantly greater in post PHV girls compared to mid PHV girls ($p<0.05$). With regards to kinetic variables, *Pmax* and *Fo* were significantly greater in post PHV girls compared to mid PHV girls ($p<0.05$). Based on the regression analysis, contact time, maximal power, step frequency, leg length, and step length were found to predict maximal sprinting speed in mid and post PHV girls. However, out of all variables, contact time and power max predicted maximal velocity for both 15 and 30 m, with contact time being the best predictor across all variables for both 15 and 30 m. Therefore, developing these kinematic and kinetic factors associated with sprinting particularly reducing ground contact time can be beneficial in overall development of sprinting in mid and post PHV girls.

Chapter 6: The effects of strength and plyometric training on sprinting kinetics in post peak height velocity females

Preface

The previous chapter used a cross-sectional approach to investigate the kinetics and kinematics of sprinting speed across maturation in this cohort. This chapter reported that step length, *Fo, Pmax, Vo* and maximal velocity were significantly higher in post PHV girls compared to mid PHV. In addition, the findings of this chapter suggest that decreasing ground contact time, increasing step length, frequency, and *Pmax* can increase maximal velocity across maturity in young females. Therefore, suggesting that progressive ST and PT that can positively influence the kinetic and kinematic variables of sprinting might improve sprinting performance in young females.

Introduction

A variety of training methods such as fundamental movement skill, coordination, stabilization, and proprioception training have been successfully implemented to improve sprinting speed in youth (Oliver, Lloyd, & Rumpf, 2013; Van Beurden et al., 2002; Kilding, Tunstall, & Kuzmic, 2008). However, resistance training comprising of PT and ST have been reported to improve speed for youth athletes across different levels of maturation (Kotzamanidis, 2006; Meylan & Malatesta, 2009; Christou et al., 2006; Coutts et al., 2004; Lloyd et al., 2016a). The use of PT and ST can enhance neural characteristics and force-generating capacity that can positively influence kinematics and kinetics of sprinting speed in youth (O'Brein et al., 2010a; Vanttinen et al., 2011).

Research has shown that a well-supervised resistance training programme that is developmentally appropriate can be safe and effective in improving physical performance measures in children and adolescents (Lloyd et al., 2014; Lloyd & Oliver, 2012). Furthermore, many forms of resistance training such as traditional strength training (lifting moderate to heavy loads using free weights and machine), weightlifting (explosive movements comprising of clean, snatch and jerk variations), plyometrics (high-speed movements comprising of jumping, bounding, and hopping) and combined ST and PT have been beneficial in eliciting positive neuromuscular response in youth (Meylan et al., 2014; Lloyd et al., 2012; Kraemer & Ratamess, 2004; Chouachi et al., 2014). More specifically, jumping exercises wherein the SSC muscle action can improve impulse-dependent components may possibly achieve better transfer to tasks such as sprinting (Yanci et al., 2016). Even though these studies have reported the neuromuscular efficacy of strength and power, limited studies have compared the effects of ST and PT on sprinting speed in youth (Lloyd et al., 2016a).

Maturation can play a significant role in neuromuscular adaptation among youth athletes (Behringer et al., 2011). This is due to the heightened neural plasticity and increased sensitivity for motor control adaptation during childhood (pre-peak height velocity- PHV) and enhanced hormonal profile with greater muscle mass seen in adolescence (mid and post PHV) (Behringer et al., 2011). Lloyd et al. (2016a) reported a significant change in sprinting speed (20 m) in pre PHV boys after 6 weeks of PT whereas combined (strength & plyometric) training elicited significant gains in sprinting speed among post PHV boys after 6 weeks of training ($p \leq 0.05$). This finding indicates that PT may be more effective in eliciting short-term gains in boys who are pre PHV and that strength may be required along with PT for post PHV in boys due to the hormonal changes. Other studies have also reported that both ST and PT can be of benefit in increasing sprinting speed in young males (Contreras et al., 2017; Chelly et al., 2009; Coutts et al., 2004; Diallo et al., 2001; Gonzalo-Skok et al., 2019; Franco-Marquez et al., 2015).

Despite some research completed in boys, there are limited studies on the effects of ST and PT on sprinting speed in young females as reported in Chapter 3, particularly ST (González-García et al., 2019). Of the few studies to date, Hopper and colleagues (2017) reported significant positive change in 20 m sprinting speed in junior netball players after 6 weeks of neuromuscular training comprising strength and plyometric activities ($p \leq 0.05$, $g > -1.2$). Similarly, Myer et al. (2005) and Siegler et al. (2003) also found significant improvements in sprinting speed (9.1, 10 and 20 m) when using a combination of ST and PT in young female athletes ($p < 0.01$). In addition, Bogdanis et al. (2019) and Chaabene et al. (2019) also reported positive changes in 10 m (*d*=1.10), 20 m (*d*= 1.14) in pre PHV gymnasts and 5 m (ES: 0.81), 10 m (ES: 0.84), 20 m (ES: 0.56) in post PHV handball players after 8 weeks of PT respectively. However, while research has investigated the effects of strength, plyometric, or combined ST and PT on sprinting speed in young girls, no previous work has compared the two methods. Therefore, this study was designed to address two questions a) does 7-weeks of ST and PT improve isometric strength, sprinting kinetics and unilateral horizontal jump distance in post PHV female athletes? and b) Is ST or PT more effective in improving sprinting kinetics in post PHV female athletes?

Methods

Experimental Approach to the Problem

To investigate these questions, two groups (ST and PT) comprised of student-athletes participated in the study along with a CON of physical education students. The ST group performed 2 sessions a week of ST for 7 weeks, whereas the PT group performed 2 sessions a week of PT for 7 weeks. The CON group continued with their regular physical education classes. The selected variables of interest (isometric strength, 30 m sprinting speed and single leg horizontal jump) were tested pre and post the 7- week intervention in all groups.

Participants

Fifty-two girls from a private secondary school volunteered to participate in this study. The girls participated in this study were student athletes from various sports (hockey, football, water polo, netball, and athletics) and physical education students. All participants were healthy with no injuries in the previous 3 months. All participants and their legal guardians were informed of the risks and benefits of participation and both legal guardians and participants provided written consent and assent to volunteer for this study. Participants characteristics are provided in table 6.1. The study was approved by the Auckland University of Technology Ethics Committee. Participants were randomly divided into two groups: ST and PT. The CON group consisted of regular physical education students.

Procedures

Participants were tested for anthropometrics (height, weight, and seated height), 30 m sprint speed, strength (isometric mid-thigh pull), and jump (single leg horizontal jump) before and after a 7-week training intervention (Tables 6.2 and 6.3). Testing sessions began with a standardised warm-up, including 20 m multi-directional runs (forward, backward and shuffle), dynamic stretching and a series of sub-maximal sprints (50%, 75%, 90% effort). To control for environmental conditions as much as possible, testing sessions were performed at approximately the same time of the day. A familiarisation session was conducted 2 days before any data were collected. Participants completed the battery of tests in the following order: anthropometrics, 30 m sprints, single leg jumps (SLJs), and isometric mid-thigh pull. A detailed description for each test is provided below.

Anthropometry

Anthropometric measurements and date of birth were taken before familiarisation. Height (cm), sitting height (cm), leg length and mass (kg) were measured. The maturity status of the female participants was calculated using the equation of Mirwald et al. (2002). This method is considered non-invasive and practical, predicting years from PHV as a measure of maturity offset using anthropometric variables. Participants are classified into one of three groups: pre PHV velocity (-3 years to -1 years from PHV), mid PHV (-1 to +1 years from PHV), and post PHV (+1 to +3 years from PHV) (Rumpf et al., 2012). The equation for maturity offset for girls is provided below. The average maturity offset was ≥1.3 indicating that participants involved in this study were post PHV as seen in Table 6.1.

Table 6.1: Descriptive statistics of participants per group

Group	**Height (m)**	**Body Mass (Kg)**	**Age (years)**	**Maturity Offset (years from PHV)**
Strength (n=16)	1.61 ± 0.07	49.65 ± 9.18	13.36 ± 0.84	1.31 ± 0.82
Plyometric (n=21)	1.61 ± 0.06	49.97 ± 7.87	13.38 ± 0.75	1.33 ± 0.73

Control (n= 15)	1.60 $\pm$ 0.06	57.40 $\pm$ 11.73*	13.95 $\pm$ 0.54	1.71 $\pm$ 0.64

* $p<0.05$

30 m Sprinting test

Sprinting speed over a distance of 30 m was assessed using a radar gun (Version 5.0.2.1, Applied Concepts, Inc, Texas, USA) to determine kinetic variables such as *Fo*, *Vmax*, *Pmax* and 10, 20 and 30 m split times. Participants sprinted from a static split stance position with their leading foot immediately behind the start line. A radar gun (Version 5.0.2.1, Applied Concepts, inc, Texas, USA) with a sampling rate of 47 Hz, placed 5 m directly behind the start line, was used to measure sprinting speed. The operating range of the gun was set at 0 m/s (low-from zero acceleration starting position) to 14 m/s (high- typical top end speed that is not surpassed). The gun was set on a tripod set at 0.9 m above ground to approximately align with the centre of mass of the participants (Morin et al., 2006). No false start was allowed and participants were instructed to sprint maximally to a fixed marker 5m past the 30m mark (Simperingham et al., 2017). Participants performed two maximal sprints separated by 5 min of passive rest and the best of the two based on all dependent variables were taken for analysis.

Horizontal velocity was measured continuously using the radar device connected to a laptop running Stalker ATS System software (Version 5.0.2.1, Applied Concepts Inc, Texas, USA) (Simperingham et al., 2017). The raw data files were automatically processed using the digital filter “dig light”. This function is available within the software and precisely removes noise frequencies while preserving data frequency being measured. The dig light filter applies minimal filtering and suitable for “clean” radar data and applies a fourth order (one round trip), Butterworth low-pass zero lag filter with a cut off frequency of 8 Hz. To improve consistency all trials were nominated to be acceleration runs hence forcing the start of the velocity-time curve through the zero point (Simperingham et al., 2017). The processed data were then imported into a custom-made Lab View (Version 13.0, National Instruments, Corporation, Texas, USA) to calculate all outcome variables (*Fo, Vo, Pmax, Vmax* and split times between 0 and 30 m) (Buchheit et al., 2014; Cross et al., 2015; Morin & Seve, 2011). The velocity-time curve [v(t)] for each sprint was calculated using the exponential function $v(t)= Vmax \times (1 - e^{-t/\tau})$ (Al Haddad, Simpson, & Buchheit, 2015), horizontal acceleration was calculated from Newton's second law of motion Fh(t) = [m × a(t)] + Fair(t) (Arsac & Locatelli, 2002) and Pmax was calculated through the equation *Pmax* = (0.5× *Fo*) × (0.5× *Vo*) (Bezodis et al., 2012). Data recorded for both the trials were used in the assessment of intra-day and the best trials on each for the inter-day reliability. A moderate to strong ICC = 0.74-0.98 with a CV ranging from 1.70-12.70% across all kinetic variables (*Fo, Vo, Vmax, Pmax*, 10, 20, and 30 m split times) were reported for both intraday and inter-day reliability in this population (see Chapter 4).

Single leg horizontal jump

Each participant began the test by standing on their chosen leg with the toe at the starting line. Participants were instructed to sink to a self-selected depth before the jump as quickly as possible and land on 2-feet. Jump distance was measured to the nearest 0.01 m with a tape measure. Participants were given three attempts on each leg and the best attempts were recorded (Meylan et al., 2009). The reliability between attempts for both legs were acceptable ICC =0.78 and CV ranging from 2.65 to 8.3% in this study. Single leg horizontal jump test has also been reported to be highly reliable in adult male and females with ICC ranging from 0.95 to 0.97 and CV ranging from 2.7 to 3.1% (Meylan et al., 2009).

Isometric mid-thigh pull

Isometric mid-thigh pull (IMTP) testing was performed using a portable force plate interfaced with computer software (Ballistic Measurement System, Innervations, Australia). Data were filtered using a fourth-order Butterworth filter with a 16 Hz cut off frequency (Thomas et al., 2015). An immovable bar was positioned at the mid-thigh region above the force platform, then adjusted according to the height of the participants (Thomas et al., 2015). The force plate was zeroed before the participants stepped onto the force platform. Participants then stood on the force platform with their hands gripping (prone grip) the bar (Thomas et al., 2015) and performed two warmup pulls at 50% and 75% of their perceived maximum effort, separated by 1 minute of rest (Thomas et al., 2015). The set up included participants placing their feet hip width apart, while the bar was positioned at midthigh and the torso was upright with a neutral spine (Moeskops et al., 2018). The customised portable IMTP allowed for incremental bar adjustments to accommodate participants of different statures (Moeskops et al., 2018). Instructions were provided to pull maximally by applying force quickly and pushing the feet down on the force platform. Participants performed 3 maximal pull efforts for 5 seconds, separated by 1 minute of passive rest (Thomas et al., 2015). Verbal encouragement was provided during each trial and the best of the three trials was considered for analysis. Both peak force (N) and relative peak force (N/kg) were used for analysis. IMTP measures such as absolute and relative peak force have been reported to be reliable within and between sessions in pre and post PHV female athletes (ICC = 0.87 and 0.92; CV ≤ 9.4% and ≤ 7.3% respectively (Moeskops et al., 2018).

Training programmes

Both intervention groups trained twice per week for a total of 7 weeks, and training sessions were designed and implemented by an accredited strength and conditioning coach. There was a minimum of 48 hours between sessions to allow for full recovery (Lloyd et al., 2016a). All the training sessions were preceded by RAMP (raise, activate, mobilise and potentiate) based protocol of warm-up that included multi-directional runs, dynamic stretching and activation, and semi-structured games and movement exploration (see Chapter 9, Figures 9.6 and 9.7) (Jeffreys & Moody, 2016; Barreiro & Howard, 2017). In addition, participants did not perform any other training except for skill sessions throughout the intervention period. A training log was maintained to keep a track of the skill sessions outside the intervention to avoid physiological interference. The log included total training duration, and session rating of perceived exertion (SRPE) for each skill session participants performed using the modified Borg category ratio-10 (CR 10) scale (Scantlebury et al., 2017; Foster, 1998). Both ST and PT were performed in sequence i.e., moving from one exercise to another with rest of 60-120 s depending on the phase, intensity and complexity of the movements.

Strength Training

The ST programme comprised of lower and upper body exercises as shown in Table 6.2. More specifically, lower body training included vertical, horizontal, bilateral and unilateral exercises, whereas upper body training included multi-joint horizontal pushing and pulling exercises. The load progressed gradually every week (10-20%) for the lower body and (5-10% number of repetitions) for the upper body as long as participants could maintain technical competency for all the exercises (Lloyd et al., 2016a). For example, maintaining a neutral spine while performing goblet squats. The loads were individually adjusted based on competency. If participants could not demonstrate good technical competency in lifting, then the resistance load was reduced. In addition, assistance was provided if any participant could not perform any movements due to restriction. For example, heel lift was provided for goblet squats for individuals who were limited due to ankle dorsiflexion range of motion (see Chapter 9, Figure 9.1).

Table 6.2: Overview of the strength training programme

Exercise	Sets	Repetitions	Progression
Goblet Squat (vertical lower body)	Week 1-3: 4 Week 4-7: 5	5	Increase load 10-20%, move to Trap bar
Push Up (upper body push)	Week 1-3: 4 Week 4-7: 5	Week 1-3: 5 Week 4-7: >5	Feet elevated and increase repetitions
Split Squat (unilateral lower body)	Week 1-3: 4 Week 4-7: 5	5 each	Increase load by 10-20%
Suspension row (upper body pull)	Week 1-3: 4 Week 4-7: 5	Week 1-3: 5 Week 4-7: >5	Feet elevated and increase repetitions
Hip raise (horizontal lower body)	Week 1-3: 4 Week >3: 5	5	Increase load by 10-20%

Plyometric training

The PT programme included a combination of upper and lower body exercises that emphasised safe jumping, landing and throwing mechanics as shown in Table 6.3. More specifically, the programme included vertical and horizontal jump training along with upper body throwing. The repetitions and sets were gradually progressed based on foot contacts, eccentric demands, and complexity of the exercises. Movement patterns were also individually progressed based on competency. For example, individuals who could not perform repeated bounding over hurdle, started with sticking the landing initially for better control (see Chapter 9, Figure 9.5).

Table 6.3: Overview of the plyometric and power training programme

Exercise	Sets	Repetitions	Progression
Box jump (vertical jump)	Week 1-3: 4 Week 4-7: 5	5	Increase height
Medicine ball slams (vertical upper body)	Week 1-3: 4 Week 4-7: 5	5	Increase weight
Single leg bounds (unilateral horizontal)	Week 1-3: 4 each Week 4-7: 5 each	5 each	Increase total distance of bounds
Hurdle jumps (**horizontal bilateral And unilateral)**	Week 1-3: 4 Week 4-7: 5	5	Repeated/unilateral (low ground contact time)
Broad jump (bilateral horizontal)	Week 1-3: 4 Week 4-7: 5	5	Increase distance

Statistical Analysis

Means and SD were calculated for all dependent variables of interest as measures of centrality and spread of data. Levene's test was used to check homogeneity of variance across samples. Paired t-tests were used to determine significant differences across variables of interest for pre and posts scores for all groups. ESs were calculated for all performance variables in each training group and assessed using the magnitude of ESs according to Cohen's *d* statistic (Cohen, 1988). ES were classified as follows trivial ≤0.19), small (0.20 to 0.59), moderate (0.60 to 1.19), large (1.20 to 1.99), and very large (2.0 to 4.0) (Hopkins, 2002). Hedge's *g* was also calculated due to smaller sample sizes (Lakens, 2013). Descriptive statistics, ANOVA and paired t-tests were computed using SPSS V.25 (SPSS Inc, Chicago, IL, USA), with statistical significance for all tests set at an alpha level of $p \leq 0.05$. A one-way analysis of variance (ANOVA) was used to determine significant differences between the groups. Bonferroni post hoc and Dunnett's tests were used to correct error rate and provide specific comparisons between the groups i.e. PT vs. ST vs. CON.

Results

Mean changes in the dependent variables for all groups are displayed in Table 6.4**,** 6.5 and 6.6 respectively. Individual changes in sprinting kinetics from pre to post are shown in Figure 6.1-6.4 for the intervention groups. There were significant changes across the groups in all variables from pre to post testing with ES ranging from trivial (*d*=0.14; *g*=0.14) to moderate **(***d*= 0.81; *g*=0.78) ($p<0.05$). The PT group significantly improved *Vmax, Fo, Pmax,* IMTP and SLJ (both sides) with ES ranging from *d*=0.26; *g*=0.26 to *d*= 0.59; *g*= 0.57 ($p<0.05$**).** No changes were seen in split times. The ST group significantly improved *Fo*, 10 m split time, IMTP and SJ **(**both sides) with ES ranging from *d*=0.44; *g*= 0.43 to *d*= 0.67; *g*= 0.65 ($p<0.05$). No changes were seen in *Vmax, Pmax*, 20 and 30 m split times. In contrast, the CON group had significant negative changes across all variables except *Vmax*, SJ, and IMTP with ES ranging from *d*= 0.18; *g*= 0.17 to *d*= -0.81; *g*= -0.78 ($p<0.05$).

Table 6.4: Means, % changes, Confidence limits (Cl), and effect size (ES) pre and post-test for PT group

Variable	PT (pre)	Cl 95% (Lower)	Cl 95% (Upper)	PT (post)	Cl 95% (Lower)	Cl 95% (Upper)	%Change	ES
***Vmax* (m/s)**	6.32 ± 0.59	6.05	6.59	6.63 ± 0.62	6.34	6.91	4.91*	*d*=0.51, *g*=0.50
***Fo* (n)**	272.82 ± 67.16	242.25	303.40	303.16 ± 82.38	265.66	340.66	11.12*	*d*=0.40, *g*=0.40
***Pmax* (w)**	448.24 ± 124.86	391.41	505.08	483.56 ± 143.48	418.25	548.88	7.88*	*d*=0.26, *g*=0.26
10 m (s)	2.76 ± 0.36	2.60	2.92	2.71± 0.34	2.55	2.86	1.81	*d*=0.14, *g*=0.14
20 m (s)	4.39 ± 0.44	4.19	4.59	4.29 ± 0.42	4.10	4.49	2.27	*d*=0.23, *g*=0.23
30 m (s)	5.96 ± 0.54	5.71	6.20	5.84 ± 0.54	5.59	6.08	2.01	*d*=0.22, *g*=0.22
IMTP (N)	738.62 ±166.37	662.89	814.35	836.33 ± 195.18	747.49	925.18	13.23*	*d*=0.54, *g*=0.53
Rel IMTP (N/kg)	15.12 ± 4.62	13.02	15.19	17.23 ± 5.47	14.73	19.71	13.96*	*d*=0.41, *g*=0.41
SJ R (m)	1.61 ± 0.21	1.52	1.70	1.73 ± 0.20	1.64	1.82	7.45*	*d*=0.59, *g*=0.57
SJL (m)	1.63 ± 0.17	1.55	1.70	1.71 ± 0.16	1.64	1.78	4.91*	*d*=0.55, *g*=0.53

*p<0.05; ES- effect size, d= Cohen's d, g=Hedge's g, *Vmax*- velocity max, *Fo*- Force, *Pmax* - Power max, IMTP- isometric midthigh pull, Rel IMTP- relative isometric midthigh pull, SJR- Single leg jump right, SJL- Single leg jump left

Table 6.5: Means, % changes, Confidence limits (Cl), and effect sizes pre-and post- test-for ST group

Variable	ST (pre)	CI 95% (Lower)	CI 95% (Upper)	ST (post)	CI 95% (Lower)	CI 95% (Upper)	%Change	ES
***Vmax* (m/s)**	6.48 ± 0.45	6.24	6.71	6.56 ± 0.55	6.27	6.86	1.23	*d*=0.16, *g*=0.16
***Fo* (n)**	262.41 ± 69.74	225.25	299.57	305.35 ± 58.21	274.33	336.37	16.36*	*d*=0.67, *g*=0.65
***Pmax* (w)**	462.23 ± 147.38	383.70	540.76	494.63 ± 123.30	428.92	560.33	7.01	*d*=0.24, *g*=0.23
10 m (s)	2.81 ± 0.39	2.60	3.01	2.62 ± 0.11	2.57	2.68	6.76*	*d*=0.66, *g*=0.65
20 m(s)	4.37 ± 0.45	4.14	4.62	4.20 ± 0.17	4.11	4.29	3.89	*d*=0.50, *g*=0.49
30 m(s)	5.90 ± 0.53	5.62	6.18	5.73 ± 0.26	5.59	5.87	2.88	*d*=0.41, *g*=0.40
IMTP (N)	698.11 ± 137.04	625.08	771.13	807.37 ± 195.77	703.05	911.68	15.65*	*d*=0.65, *g*=0.63
Rel IMTP (N/kg)	14.24 ± 2.69	12.81	15.68	16.54 ± 4.46	14.17	18.91	16.15*	*d*=0.62, *g*=0.61
SJ R (m)	1.59 ± 0.19	1.48	1.69	1.67 ± 0.17	1.58	1.76	5.03*	*d*=0.44, *g*=0.43
SJL (m)	1.61 ± 0.16	1.52	1.69	1.70 ± 0.18	1.60	1.80	5.59*	*d*=0.53, *g*=0.52

*p<0.05; ES- effect size, d= Cohen's d, g=Hedge's g, *Vmax*- velocity max, *Fo*- Force, *Pmax* - Power max, IMTP- isometric midthigh pull, Rel IMTP- relative isometric midthigh pull, SJR- Single leg jump right, SJL- Single leg jump left

Table 6.6: Means, % changes, Confidence limits (Cl), and effect sizes pre-and post- test-for CON group

Variable	CON (pre)	Cl 95% (Lower)	Cl 95% (Upper)	CON (post)	Cl 95% (Lower)	Cl 95% (Upper)	%Change	ES
***Vmax* (m/s)**	6.02 ± 0.37	5.81	6.23	5.94 ± 0.52	5.65	6.23	-1.33	*d*=0.18, *g*=0.17
***Fo* (n)**	304.33 ± 64.82	268.44	340.23	267.60 ± 65.45	231.35	303.85	-12.07*	*d*=0.56, *g*=0.55
***Pmax* (w)**	455.47 ± 86.97	407.30	503.63	394.33 ± 90.53	344.20	444.47	-13.42*	*d*=0.69, *g*=0.67
10 m (s)	2.77± 0.19	2.67	2.87	2.94 ± 0.23	2.82	3.07	-6.14*	*d*=0.81, *g*=0.78
20 m(s)	4.45 ± 0.26	4.31	4.59	4.64 ± 0.28	4.48	4.79	-4.27*	*d*=0.70, *g*=0.68
30 m(s)	6.12 ± 0.36	5.92	6.32	6.30 ± 0.39	6.08	6.51	-2.94*	*d*=0.48, *g*=0.47
IMTP (N)	709.43 ± 179.25	610.17	808.69	744.96 ± 196.01	636.42	853.51	5.01*	*d*=0.19, *g*=0.18
Rel IMTP (N/kg)	12.62 ± 3.24	10.83	14.41	13.24 ± 3.44	11.33	15.14	4.91*	*d*=0.19, *g*=0.18
SJ R (m)	1.40 ± 0.16	1.32	1.49	1.44 ± 0.16	1.35	1.53	2.86	*d*=0.25, *g*=0.24
SJL (m)	1.41 ± 0.15	1.33	1.50	1.44 ± 0.16	1.36	1.53	2.13	*d*=0.19, *g*=0.19

`*p<0.05; ES- effect size, d= Cohen's d, g=Hedge's g, *Vmax*- velocity max, *Fo*- Force, *Pmax* - Power max, IMTP- isometric midthigh pull, Rel IMTP- relative isometric midthigh pull, SJR- Single leg jump right, SJL- Single leg jump left

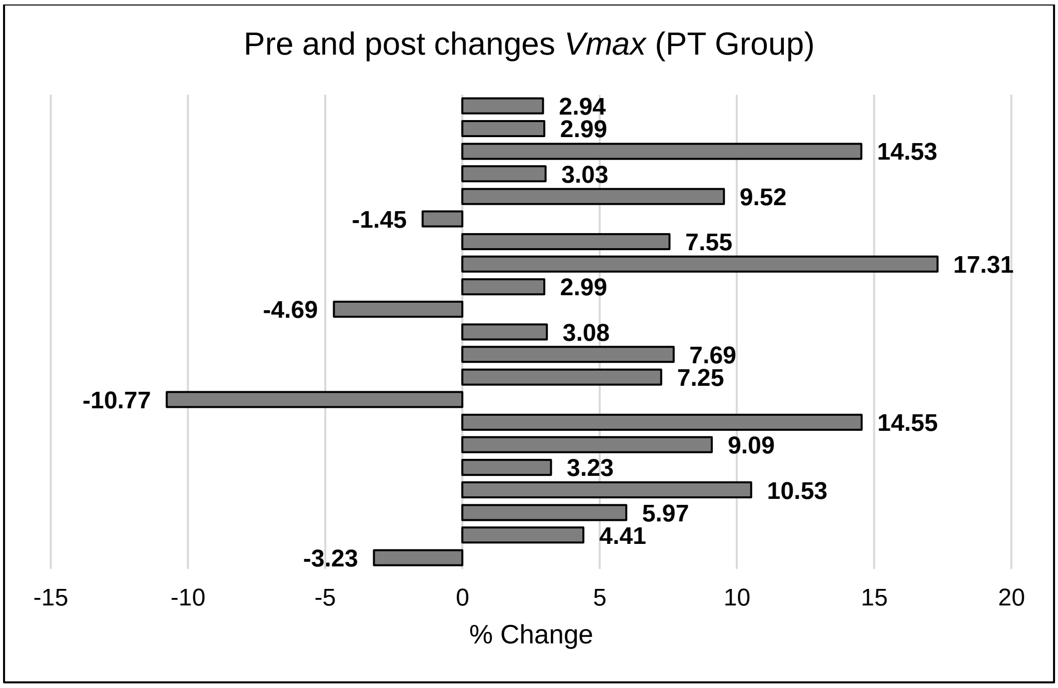

Figure 6.1: Individual *Vmax* changes in PT Group

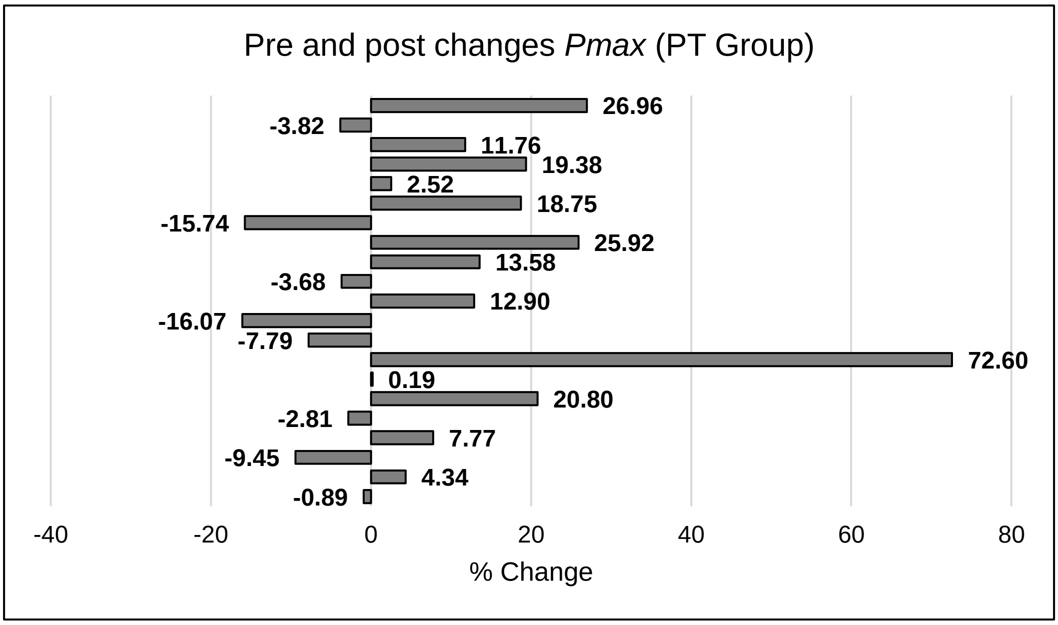

Figure 6.2 : Individual *Pmax* changes in PT Group

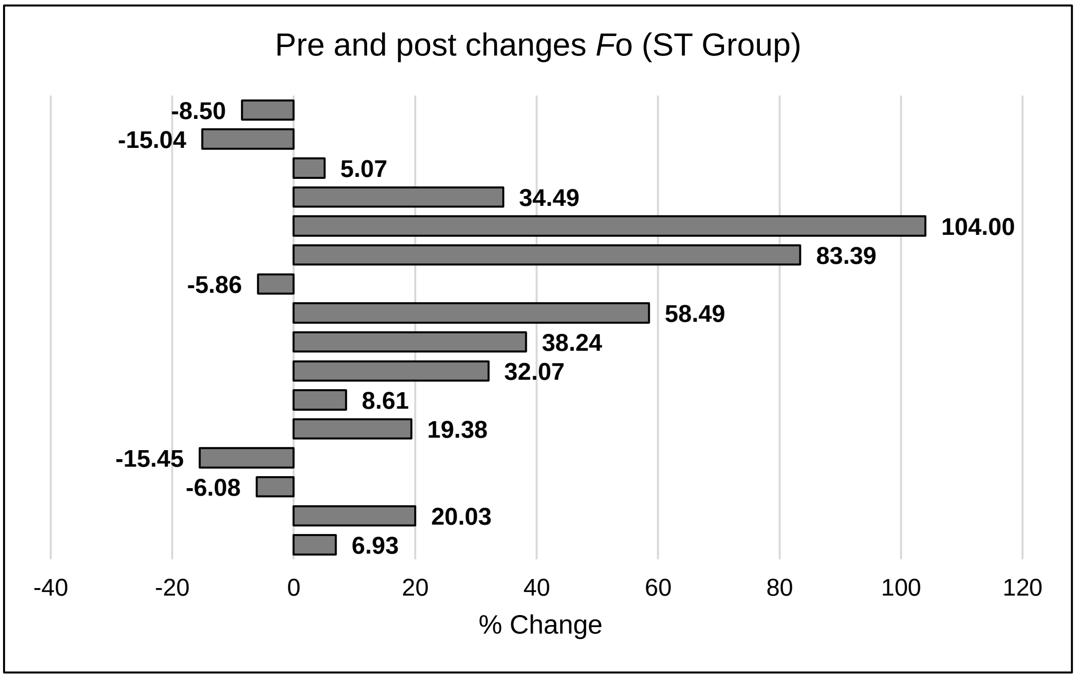

Figure 6.3: Individual *Fo* changes in ST Group

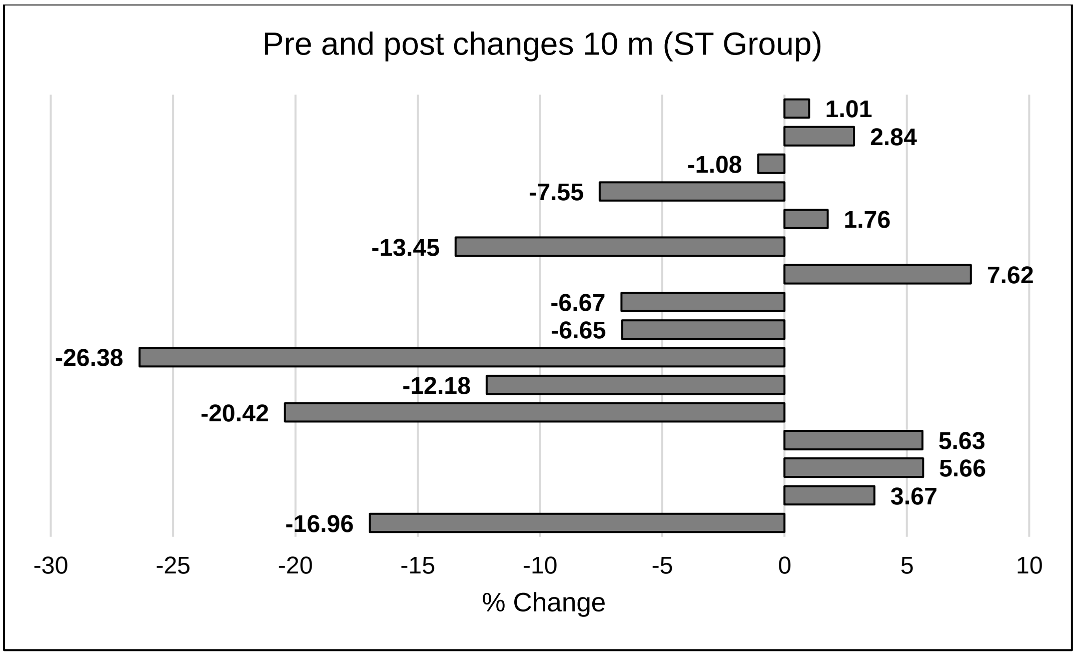

Figure 6.4: Individual 10m split time changes in ST Group

The Post hoc analysis showed that both ST and PT groups had significantly higher post scores for *Vmax,* 30, 20, 10 m split times and SLJ (both sides) compared to the CON ($p<0.05$). In addition, both the intervention groups had significantly higher scores for SLJ (both sides) in the pre-test compared to the CON group, and ST group had significantly higher score in the pre-test for *Vmax* compared to the CON group ($p<0.05$). There was no significant difference between the intervention groups for both pre and post tests across all variables. Between group differences from ANOVA are provided in Table 6.7.

Table 6.7: ANOVA results between group comparisons

Variables	Group differences
Vmax pre	F (2, 49) =3.43, p=0.04
Vmax post	F (2, 49) =7.17, p=0.00
10 m post	F (2, 49) =6.59, p=0.00
20 m post	F (2, 49) =7.85, p=0.00
30 m post	F (2, 49) =7.70, p=0.00
SJR pre	F (2, 49) =5.84, p=0.01
SJR post	F (2,49) =12.04, p=0.00
SJL pre	F (2,49) =8.66, p=0.00
SJL post	F (2,49) =13.71, p=0.00
Rel IMTP post	F (2,49) =3.46, p=0.04

Discussion

The purpose of this study was to compare the effects of ST and PT on speed and strength measures in young females. The major finding of this study was that individuals in both training groups improved sprinting performance and kinetics compared to the individuals in the CON who participated in normal physical education**.** Moreover, compared to the PT, the ST group significantly improved 10 m split time and *Fo* but not Vmax. The PT group significantly improved *Vmax, Pmax*, and *Fo* but not split times. Therefore, specific changes in sprinting kinetics appeared to occur depending on the intervention.

Findings from this study revealed that the PT group made significant improvements in *Vmax*, *Fo,* and *Pmax* with small ES (<0.60*)* but not split times ($p<0.05$*).* The individual changes for *Vmax* and *Pmax* for the PT group ranged between -10.77% to 17.31% and -16.07% to 72.60% respectively as seen in (Fig 6.1 and 6.2). In comparison, previous research has also reported trivial effects (<0.20) for split times (5, 10 and 20 m) and small effects (<0.60) for *Fo, Vo,* and *Pmax* in club level male and female athletes after 12 sessions of resisted sprint training (Cross et al., 2018). In youth populations, Kotzamanidis (2006) found significant improvements in 30 m sprint time but not for the initial 10 m after 10 weeks of PT in pre PHV boys ($p<0.05$). Similarly, Lloyd et al. (2016a) reported trivial ES for 10 m speed (d = 0.06*)* but larger ES (d = 0.34) for 20 m in young males after a 6-week PT programme. The ES for pre to post 10 m speed in the PT group in this study was also trivial (d= 0.14) compared to 20 and 30 m speed in this study (d=0.23 and d=0.22 respectively). Taken together, these findings suggest that PT has a limited effect on the initial phase of sprinting (acceleration) in youth populations.

In contrast, findings from this study showed that ST significantly improved 10 m split time and *Fo,* but not *Vmax*, *Pmax*, 20, and 30 m split time ($p<0.05$). The individual changes for *Fo* and 10 m split time ranged between -15.45% to 104.00% and -7.62% to 26.38% (Fig 6.3 and 6.4). Due to the importance of force in overcoming inertia during the initial phase of acceleration, an increase in overall force output likely contributed to the improvement seen in 10 m speed in this group. This finding is in agreement with previous research that has reported significant changes in 10 m sprinting performance after 6 to 9 weeks of traditional vertical and horizontal strength training in post PHV male athletes (Contreras et al., 2017; Coutts et al., 2004) ($p<0.05$). In the present study, ES were higher for *Fo* and 10 m speed (*d*=0.67, *g*=0.65; *d*=0.66, *g*=0.65 respectively) compared to other kinetic variables, further confirming that increases in horizontal force in this group contributed to a faster 10 m time. Similarly, a recent study reported hip thrust to be an effective exercise to improve sprint speed in post PHV female soccer players over 10 m (*d*=0.70) (González-García et al., 2019). In comparison, Lloyd et al. (2016a) reported comparatively lower ES for 10 m speed (*d* = 0.34*)* after 6 weeks of ST in post PHV boys. The disagreement in findings may in part be due to the duration of the two studies (6 versus 7 weeks) for Lloyd at al. (2016a) and the present study respectively, and a difference in weekly load. Specifically, a 5% increment was used for the exercises in Lloyd et al. (2016a) compared to 10 to 20% increment for the lower body in this study. It appears that training duration and load can significantly affect speed and power outcomes and, therefore, should be carefully considered by practitioners working with young athletes.

Similar improvements were shown in SLJ scores for ST and PT ($p<0.05$, *d*=0.44, *g*=0.43 to *d*=0.59, *g*=0.57). Previous research by Contreras et al. (2017) and Asadi et al. (2018) also reported positive changes in standing long jump after 6 weeks of ST and PT in post PHV males respectively (*d*=0.51 and *d*=0.70 respectively). In comparison, Faigenbaum et al. (2007) showed that a combination of ST and PT was more useful at improving jumping performance in young males after 6 weeks of training compared to ST alone (6.0% vs. 1.1%). The collective findings of these studies suggest that both ST and PT can improve horizontal jump performance in youth.

Furthermore, with regards to isometric strength, both absolute and relative strength was improved following ST and PT. However, this change was observed to a greater extent in the ST group (15.65 and 16.15%; *d*=0.65, *g*=0.63 and *d*=0.62, *g*=0.61 respectively) compared to the PT group (13.23 and 13.96%, *d*=0.54, *g*=0.53 and *d*=0.41, *g*=0.41 respectively). This finding is in agreement with Secomb et al. (2017) who reported greater changes in IMTP after 7 weeks of ST compared to PT and gymnastic training in adolescent athletes ($p<0.01$). It is possible that greater changes in strength seen after ST in both studies was due to improved motor unit activation, coordination, specificity of training and possible qualitative muscle changes (Ramsay et al., 1990; Ozmun, Mikeseky, & Surburg, 1994; Faigenbaum et al.,1999; Contreras et al., 2017). These findings would suggest that while both ST and PT can increase isometric strength in youth populations, ST is more effective.

The current study revealed that normal physical education led to decrements in all kinetic variables of sprinting. More specifically, the biggest decrements in this study were seen in 10 m speed (-6.14%), *Fo* (-12.07%) and *Pmax* (-13.42%). Previous research by Kotzamanidis (2006) reported decrements in 30 m speed (-0.5 to -2.35%) in young boys after 10 weeks of physical education class. The decrements in sprinting kinetics in the PE group in this study could be because PE classes included non-sprinting specific activities with an emphasis on endurance such as aquathon and cross country running as part of Physical Education curriculum. Moreover, unlike IMTP and SLJs, instant feedback was not provided after each sprint regards to scores for all the groups, that can hinder activity awareness thus affecting motivational levels in the PE group for the sprinting related variables (Bice, Ball, & McClaran, 2015). In addition, in ability to produce force in the right direction during the initial phase of the sprint among the CON group could have also negatively impacted 10 m speed, *Fo* and *Pmax* in this study.

While participants in CON got slower, absolute and relative isometric strength improved significantly (5.01% and 4.91%, $p<0.05$). Faigenbaum et al. (1999) also reported positive changes in lower and upper body 1 repetition max strength after 8 weeks of normal physical education class in young boys and girls. The increase in strength seen in the CON group of the present study may be a result of growth and maturity**,** the documented increase in isometric strength that accompanies these biological changes (Faigenbaum et al.,1999). The CON group in this study was also significantly heavier than the intervention groups ($p<0.05$). This may have also influenced the IMTP results as greater body mass can positively influence absolute strength levels. In addition, there were no meaningful changes in SLJ performance in this group. Previous research has also reported no change in horizontal jump in young males after 6 weeks of general soccer training in the control group (Asadi et al., 2018). These results suggest that an increase in isometric strength alone is not enough to improve dynamic tasks with high levels of coordination and skill, such as sprinting and SLJ, and that more specific training may be required.

Both ST and PT groups had significantly higher post scores with regards to *Vmax*, 30, 20, 10 m split times, and pre, post scores of single-leg jumps compared to the CON group (p<0.05). In addition, the relative IMTP post scores were significantly higher in PT group compared to the CON group. This might be because the CON group had significantly higher body mass compared to the intervention groups specifically the PT group. There were no significant differences across variables between the ST and PT groups. Previous researchers have also reported significant improvements in jumping and sprinting performance in boys across maturation after 6 weeks of ST, PT and combined (ST and PT) compared to a CON group (ES = 0.36-0.77 vs. ES = 0.00-0.04) (Lloyd et al., 2016a). Similarly, Asadi et al. (2018) also reported significant changes in 20 m sprint, vertical and horizontal jumps in young soccer players across maturation after 6 weeks of PT compared to the CON group (p≤0.05). Moreover, in young females, researchers have also reported combined ST and PT for a duration of 6 weeks to be effective in improving sprinting speed, strength and power measures compared to CON groups (p<0.05) (Hopper et al., 2017; Myer et al., 2005). Therefore, it seems that both ST and PT can be useful in improving sprinting speed, strength and power in the youth population. Future research should incorporate both static and rolling starts as measures of sprinting speed and their interaction with ST and PT in young female athletes. Finally, due to the importance of horizontal force production in sprinting, research investigating the use of ST exercises such as sled pushing and pulling with young female athletes is warranted.

Conclusion

Sprint kinetics, isometric strength and SLJ performance are improved in post PHV female athletes after both ST and PT. Because it is important to overcome inertia and increase propulsive forces when accelerating from a static position, ST is most helpful at improving time over 10 m and *Fo*. PT, on the other hand, is most beneficial for improving maximal power and velocity. Accordingly, it is recommended that practitioners incorporate both ST and PT to increase speed when working with post PHV female athletes. Care should be taken to gradually progress intensity, complexity, and volume of training based on the individual competence and training age of the athletes. In addition, the inclusion of semi-structured games and movement exploration as part of the warm-up can be a useful strategy to keep young females engaged particularly during strength training sessions. Future research should incorporate both static and rolling starts as measures of sprinting speed and their interaction with ST and PT in young female athletes. Finally, due to the importance of horizontal force production in sprinting, research investigating the use of strength training exercises such as sled pushing and pulling with young female athletes is warranted.

Chapter 7: The effects of horizontal and vertical plyometric training on sprinting kinetics in post peak height velocity female athletes

Preface

Chapter 6 included an intervention trial to compare the effects of ST vs. PT on sprinting kinetics in post PHV female athletes. Both ST and PT groups significantly improved sprinting kinetics along with isometric strength and unilateral horizontal jump compared to the CON group. With regards to sprinting kinetics, PT was more useful in increasing *Vmax* and *Pmax* whereas ST was more effective in improving 10 m split time and *Fo*. PT was found to be effective in improving *Vmax* and *Pmax* in the previous chapter and no study previously investigated different types of PT on sprinting kinetics in young females. Therefore chapter 7 investigated the effects of horizontal and vertical PT on sprinting kinetics in post PHV female athletes.

Introduction

Plyometric training has repeatedly been shown to improve jumping and sprinting ability in adults (Ramirez-Campillo et al., 2018; Oxfeldt et al., 2019; Saez de Villarreal, Reuena, & Cronin, 2012). Recent research has also shown plyometrics to be an effective means to improve sprinting speed in youth (Lloyd et al., 2016; Bogdanis et al., 2019; Ramirez- Campillo et al., 2015b; Gonzalo-Skok et al., 2019). PT is characterized by rapid movements that can improve neural efficiency (Davies, Riemann, & Manske, 2015). It consists of three phases: 1) the eccentric (pre-activation) phase, 2) the isometric (amortization) phase, and 3) the concentric (shortening) phase (Davies et al., 2015). This process is termed as the SSC and is considered as an integral part of PT due to the ability of the muscle tendon to produce force in the shortest amount of time (Saez de Villarreal et al., 2012). During the eccentric phase, the Golgi tendon organs are stretched more than in regular ST, which results in greater inhibition of the protective function of these organs and, thus, greater power output (Davies et al., 2015; Sale,1988). These physiological adaptations are associated with increased joint stiffness, improved muscle strength, increased contraction speed, and improved dynamic stability and neuromuscular control (Sale, 1988; Ramirez-Campillo et al., 2015b).

In the youth population, various forms of PT have been used to improve the power characteristics of athletes (Thomas, French, & Hayes, 2009; Vaczi, et al., 2013). For example, a combined vertical and horizontal PT programme significantly improved 15 m (-5.9%) and 30 m (-6.5%) sprint times in a group of 10-15 years old soccer players after 6-weeks of training compared to a control group (-0.2 and 0.4%) respectively (Ramirez-Campillo et al., 2015a). Similarly, Asadi et al. (2018) reported PT using a drop jump from various height (20, 40, 60 cm) over 6 weeks to significantly improve 20 m speed in pre, mid and post PHV male soccer players with trivial to moderate training effect ($p<0.05$). In comparison, Lloyd et al. (2016a) also reported PT that included both horizontal and vertical jumps was effective at improving sprint time for 10 and 20 m, d = 0.4 and 0.5, respectively in pre PHV boys after 6 weeks of training. Interestingly, the ES was greater for 10 m sprint time in this study for a combined ST and PT group compared to a PT training group (Lloyd et al., 2016a). This suggests that PT along with ST can be useful in improving sprinting speed in youth, particularly in young males.

Limited studies have investigated the effects of PT on sprinting speed in young females (Siegler et al., 2003**;** Myer et al., 2005; Hopper et al., 2017; Bogdanis et al., 2019; Chaabene et al., 2019). Moreover, of the studies that do exist, most have investigated PT in combination with ST (Siegler et al., 2003, Myer et al., 2005; Hopper et al., 2017). For instance, Siegler et al. (2003), Myer et al. (2005) and Hopper et al. (2017) found significant improvements in sprinting speed (distance: 9.1-20 m) over a period of 6-10 weeks of combined ST and PT ($p<0.01$). However, because a mixed training method was used in these studies it is difficult to determine the efficacy of PT alone on sprinting speed in this population.

Recently two studies have investigated the effect of PT alone on sprinting speed in young female athletes (Bogdanis et al., 2019; Chaabene et al., 2019). Bogdanis et al. (2019) reported significant changes in 10 and 20 m sprinting speed in pre PHV gymnasts after 8 weeks of PT (d= 1.10 and 1.14, $p<0.01$) for 10 and 20 m, respectively). Similarly, Chaabene et al. (2019) reported improvements in 5, 10 and 20 m sprinting speed in post PHV handball players after 8 weeks of PT (ES = 0.81 0.84 and 0.56 for 5, 10 and 20 m, respectively). However, to optimize the transfer from

PT to performance measures such as sprinting, the direction of applied force needs to be considered (Gonazlo-Skok et al., 2019). The importance of applying horizontal force to improve sprinting speed has been reported to be an optimal movement strategy as opposed to just increasing the GRFs (Morin, 2013). Accordingly, multiple studies have reported that horizontal strength exercises such as hip thrusts and plyometric exercises such as BJ and bounding can be useful in improving sprinting speed (Contreras et al., 2017; Gonzalo-Skok et al., 2019; Morin et al., 2017). In the youth population, previous researchers have reported greater improvements in sprinting speed over 5 and 25 metres with horizontal PT compared to vertical PT in young male athletes (0.8-2.2% vs.1.6- 4.9%) (Gonzalo-Skok et al., 2019). Therefore, it is believed that plyometric movements that include application of force similar to that required in sprinting positively affects sprinting speed (Young, McLean, & Ardanga, 1995).

However, to the authors knowledge, no previous studies have compared different forms of PT i.e. vertical vs. horizontal on sprinting performance in young females. Therefore, this study was designed to address two questions a) does 7-weeks of VT and HT improve isometric strength, sprinting kinetics, vertical and horizontal jump in post PHV female athletes? and b) Is VT or HT more effective in improving sprinting kinetics in post PHV female athletes?

Materials and Methods

Experimental Approach to the Problem

To investigate these questions, two groups, horizontal (HT) and vertical (VT) PT comprised of student-athletes participated in the study along with a CON group of physical education students. The HT performed 2 sessions a week of horizontal PT for a total duration of 7 weeks, whereas the VT group performed 2 sessions a week of vertical PT for a total duration of 7 weeks. The CON group continued with their regular physical education classes. The selected variables of interest (isometric strength, 30 m sprinting speed, vertical and horizontal jumps) were tested pre and post the 7- week intervention in all groups.

Participants

Twenty-one student athletes from different sports (hockey, football, netball, and water polo) and 9 physical education students from a private secondary girls' school in Auckland, New Zealand were recruited to participate in this study. Participants were randomly divided into two groups: HT and VT. The CON group consisted of regular physical education students. The participants had a minimum of 1 year of training in their respective sports. All participants were healthy with no recent (minimum of 3 months) injuries. All participants and their legal guardians were informed of the risks and benefits of participation and both legal guardians and participants provided written consent and assent to volunteer for this study. The participants' characteristics are provided in table 7.1. The study was approved by the Auckland University of Technology Ethics Committee.

Table 7.1: Descriptive statistics for anthropometrics per group

Groups	Age (years)	Mass (kg)	Height (m)	Maturity Offset (years from PHV)
HT (n=10)	13.40 $\pm$ 0.92	54.73 $\pm$ 7.16	1.65 $\pm$ 0.06	1.60 $\pm$ 0.93
VT (n=11)	13.50 $\pm$ 0.96	56.25 $\pm$ 14.87	1.64 $\pm$ 0.10	1.60 $\pm$ 1.14
CON (n=9)	15.60 $\pm$ 0.31*	57.54 $\pm$ 5.75	1.68 $\pm$ 0.06	2.90 $\pm$ 0.55*

*$P<0.05$, HT- Horizontal Training, VT- Vertical Training, CON – Control group

Procedure

Participants were tested for anthropometrics, 30 m sprint speed, strength and power before and after the 7-week training intervention. Testing sessions began with a standardised warm-up, including 20 m multi-directional runs (forward, backward and shuffle), dynamic stretching and a series of sub-maximal sprints (50%, 75%, 90% effort). To control for environmental conditions as much as possible, testing sessions were performed at approximately the same time of the day. A familiarisation session was conducted 2 days before any data were collected. Participants completed the tests in the following order: anthropometrics, 30 m sprint, vertical and horizontal jump and the isometric mid-thigh pull.

Anthropometry

Anthropometric measurements and date of birth were taken before familiarisation. Height (m), sitting height (m), leg length and body mass (kg) were measured. The maturity status of the female participants was calculated using the equation of Mirwald et al. (2002). This method is considered non-invasive and practical, and using anthropometric variables predicts years from PHV as a measure of maturity offset. According to this method, maturity status is defined as pre-PHV (-3 years to -1 years from PHV), mid-PHV (-1 to +1 years from PHV), and post PHV (+1 to +3 years from PHV) (Rumpf et al., 2012). The maturity offset for each group in the present study is shown in Table 7.1

30 m Sprinting test

Sprinting speed and a range of kinetic variables were assessed over 30 m using a radar gun (Version 5.0.2.1, Applied Concepts, Inc, Texas, USA). Participants sprinted from a static split stance position with their leading foot immediately behind the start line. The operating range of the gun was set at 0 m/s (low-from zero acceleration starting position) to 14 m/s (high- typical top end speed that is not surpassed). The radar gun, set on a tripod at 0.9 m above ground and 5 m directly behind the start line, and with a sampling rate of 47 Hz, was approximately aligned with the centre of mass of the participants (Morin et al., 2006). No false start was allowed and participants were instructed to sprint maximally to a marker 5 m past the 30m line (Simperingham et al., 2017). Participants performed two maximal sprints interspersed with 5 minutes of passive rest.

Horizontal velocity was measured continuously using the radar device connected to a laptop running Stalker ATS System software (Version 5.0.2.1, Applied Concepts Inc, Texas, USA) (Simperingham et al., 2017). The raw data files were automatically processed using the digital filter “dig light”. This function is available within the software and precisely removes noise frequencies while preserving data frequency being measured. The dig light filter applies minimal filtering and suitable for “clean” radar data and applies a fourth order (one round trip), Butterworth low-pass zero lag filter with a cut off frequency of 8 Hz. To improve consistency all trials were nominated to be acceleration runs hence forcing the start of the velocity-time curve through the zero point (Simperingham et al., 2017). The processed data were then imported into a custom-made Lab View (Version 13.0, National Instruments, Corporation, Texas, USA) to calculate all outcome variables (*Fo, Vo, Pmax, Vmax* and split times between 0 and 30 m) (Buchheit et al., 2014; Cross et al., 2015; Morin & Seve, 2011). The velocity-time curve [v(t)] for each sprint was calculated using the exponential function $v(t)= V_{max} \times (1 - e^{-t/\tau})$ (Al Haddad, Simpson, & Buchheit, 2015), horizontal acceleration was calculated from Newton's second law of motion $Fh(t) = [m \times a(t)] + Fair(t)$ (Arsac & Locatelli, 2002) and Pmax was calculated through the equation $P_{max} = (0.5\times F_o) \times (0.5\times V_o)$ (Bezodis et al., 2012). Data recorded for both the trials were used in the assessment of intra-day and the best trials on each for the inter-day reliability. A moderate to strong ICC = 0.74-0.98 with a CV ranging from 1.70-12.70% across all kinetic variables (*Fo, Vo, Vmax, Pmax*, 10, 20, and 30 m split times) were reported for both intraday and inter-day reliability in this population (see Chapter 4).

Vertical jump

Vertical jump (VJ) performance was assessed using the Just Jump System (Probiotics, US). Participants were required to step on the mat with feet parallel to each other and hips shoulder width apart. Participants were then required to perform a quick countermovement by flexing their hips and knees to a self-selected depth before explosively extending at the knees, hips and ankles to attain a maximal jump height (Nuzzo, Anning, & Scharfenberg, 2011). All participants were allowed to use arm swing for each jump (Nuzzzo et al., 2011). A total of three attempts were provided and the best result was used for analysis. The reliability between trials for VJ in this study was high (ICC= 0.94, CV= 3.60%). Previous research has also reported strong intersession reliability of VJ performance in females using the Just Jump System aged 19.5 $\pm$ 1.3 (ICC = 0.92, CV = 4.4%) (Nuzzo et al., 2011).

Horizontal jump

HJ performance was assessed using the standing long jump or broad jump (BJ). Participants stood behind a start line and were instructed to jump forwards as far as possible by pushing off the ground explosively at a self-selected depth without the hands on the hips. For a trial to count, participants had to land with the feet together without falling over. The jump distance, measured to the nearest 0.01 m with a tape measure, was taken from the take off line to where the back of the heel nearest to the take off line after landing. A total of three attempts were provided and the best of the three were considered for analysis (Fernandez-Santos et al., 2015). The reliability between trials for HJ in this study was high (ICC = 0.94; CV = 3.40%) Previous researchers have found standing HJ to be highly reliable with inter trial difference of 0.3 $\pm$ 9.0 cm in adolescent females (Ortega et al., 2008).

Isometric mid-thigh pull

Isometric strength was assessed using the IMTP. An immovable bar was positioned at the participants' mid-thigh region above a force platform interfaced with computer software sampling at 600 Hz. (Ballistic Measurement System, Innervations, Australia). Force plate was zeroed before the participants stepped onto the force platform. Participants obtained a self-selected knee and hip angle with the immovable bar resting at mid-thigh (Thomas et al., 2015). Participants stood on the force platform with their hands gripping (prone grip) the bar and performed two warmup pulls at 50% and 75% of their perceived maximum effort, separated by 1 minute of rest (Thomas et al., 2015). The set up included participants to place their feet hip width apart, the bar was positioned at midthigh and the torso was upright with a neutral spine (Moeskops et al., 2018). The customised portable IMTP allowed for incremental bar adjustments to accommodate participants of different statures (Moeskops et al., 2018). They were then instructed to pull maximally pushing the feet down on the force platform as hard as possible and applying force quickly. Participants performed 3 maximal pull efforts for 5 seconds, separated by 1 minute of passive rest (Thomas et al., 2015). Verbal encouragement was provided during each trial and the best of the three trials was considered for analysis. Data were filtered using a fourth-order Butterworth filter with a 16 Hz cut off frequency (Thomas et al., 2015). IMTP measures such as absolute and relative peak force have been reported to be reliable within and between sessions in pre and post PHV female athletes (ICC = 0.87 and 0.92; CV $\leq$ 9.4% and $\leq$ 7.3% respectively (Moeskops et al., 2018).

Training programmes

Both the intervention groups trained twice per week for a total of 7 weeks using a programme designed and implemented by an accredited strength and conditioning coach. There was a minimum of 48 hours difference between sessions to allow for full recovery (Lloyd et al., 2016a). All the training sessions were preceded by a RAMP (Raise, activate, mobilise and potentiate) based warm-up protocol that included multi-directional runs, dynamic stretching and activation, and semi-structured games and movement exploration (see chapter 9, Figure 9.6 and 9.7) (Jeffreys & Moody, 2016; Barreiro & Howard, 2017). Participants were asked not to perform any other training except for their sports skill sessions throughout the intervention period. A training log was maintained to keep a track of training sessions and activity outside the intervention to avoid physiological interference. The log included total duration, and session rating of perceived exertion (SRPE) for each skill session participants performed using the modified Borg category ratio-10 (CR 10) scale (Scantlebury et al., 2017; Foster 1998).

Vertical and Horizontal Plyometric Training

Jump training was gradually progressed throughout the intervention based on movement complexity and eccentric muscle contraction demands (Tables 7.2 and 7.3). In addition to the vertical and horizontal jumping movements (see Chapter 9, Figures 9.4 and 9.5), upper body power, strength (vertical pulling) and trunk stability (anti-lumbar extension) movements were included for both groups to ensure continued development of upper body and trunk musculature. In general, jumping volume increased from 3 sets of 5 repetitions to 5 sets of 5 repetitions by week 4. If technical competency was not achieved for any movements then a regression was provided. Once competency was achieved, complexity was added (Tables 7.2 and 7.3). Whilst no increase in the number of sets completed after week 3, number of repetitions for chin ups and stability ball roll outs were increased when technical competency was maintained. The intervention groups performed their exercises in the same order on each training occasion, separated by 60-120 s of passive rest depending on the phase, intensity, and complexity of the movements.

Table 7.2: Vertical training programme

Exercise	Sets	Reps	Progression
Countermovement jumps	Week 1-3: 3 Week 4-7: 5	5	Repeated jumps (low ground contact time)
Chin Up	3	5	Increase repetitions
Single leg box jumps	Week 1-3: 3 Week 4-7: 5	5 each	Increase height
Medicine ball slams	Week 1-3: 3 Week 4-7: 5	5	Increase load
Drop jump (vertical)	Week 1-3: 3 Week 4-7: 5	5	Increase height
Stability ball roll outs	3	10	Decrease size of ball
Squat jumps	Week 1-3: 3 Week 4-7: 5	5	Increase height

Table 7.3: Horizontal training programme

Exercise	Sets	Reps	Progression
Broad jump	Week 1-3: 3 Week 4-7: 5	5	Repeated jumps (low ground contact time)
Chin Up	3	5	Increase repetitions
Mini-hurdle jump and stick	Week 1-3: 3 Week 4-7: 5	5 each	Repeated/unilateral landing
Medicine chest throw	Week 1-3: 3 Week 4-7: 5	5	Increase load
Drop jump (horizontal)	Week 1-3: 3 Week 4-7: 5	5	Increase height
Stability ball roll outs	3	10	Decrease size of ball
Bound and stick	Week 1-3: 3 Week 4-7: 5	5	Repeated (low ground contact time)

Statistical Analysis

Means and standard deviation were calculated for all dependent variables of interest as measures of centrality and spread of data. Levene's test was used to check homogeneity of variance across samples. Paired t-tests were used to determine significant differences across variables of interest for pre and posts scores for all groups. ESs were calculated for all performance variables in each training group and assessed using the magnitude of ESs according to Cohen's *d* statistic (Cohen, 1988). ESs were classified as follows trivial (≤ 0.19), small (0.20 to 0.59), moderate (0.60 to 1.19), large (1.20 to 1.99). and very large (2.0 to 4.0) (Hopkins, 2002). Hedge's *g* was also calculated due to smaller sample sizes (Lakens, 2013). Descriptive statistics, ANOVA and paired t-tests were computed using SPSS V.25 (SPSS Inc, Chicago, IL, USA), with statistical significance for all tests set at an alpha level of $p \leq 0.05$. A one-way analysis of variance (ANOVA) was used to determine significant differences between the groups. Bonferroni post hoc and Dunnett's tests were used to correct error rate and provide specific comparisons between the groups i.e. VT vs. HT vs. CON.

Results

Mean changes in the dependent variables are displayed in Table 7.4, 7.5 and 7.6 respectively for all the groups. There were significant changes across both the intervention groups in all variables from pre to post testing ranging from small (d=0.42, g=0.40) to large (d=1.36, g=1.30) ES (p<0.05). The VT group significantly improved in all variables of interest except for *Fo* and *Pmax*, with ES ranging from d=0.33, g=0.32 to d=0.67, g=0.64. The HT group significantly improved in all dependent variables with ES ranging from d=0.49, g=0.47 to d=1.36, g=1.30 (p<0.05). Individual percentage changes from pre to post scores for the intervention groups are provided in Fig 7.1-7.4. In contrast, the CON group did not show any significant changes from pre to post testing (Table 7.6).

Table 7.4: Means, % changes, confidence intervals (CI) and effect size (ES) pre and post-test across variables for VT group

Variables	VT (pre)	CI 95% (Lower)	CI 95% (Upper)	VT (post)	CI 95% (Lower)	CI 95% (Upper)	% Change	ES
***Vo* (m/s)**	7.06 ± 0.49	6.73	7.40	7.35 ± 0.61	6.93	7.76	4.11*	*d*=0.52, *g*=0.50
***Vmax* (m/s)**	6.79 ± 0.46	6.48	7.10	7.03 ± 0.53	6.67	7.38	3.53**	*d*=0.48, *g*=0.47
***Fo* (N)**	295.54 ± 128.01	209.55	381.54	365.45 ± 261.37	189.86	541.04	23.65	*d*=0.34, *g*=0.33
***Pmax* (W)**	503.64 ± 213.77	360.02	647.25	589.09 ± 291.80	393.05	785.13	16.96	*d*=0.33, *g*=0.32
10 (s)	3.11 ± 0.50	2.77	3.44	2.83 ± 0.65	2.39	3.26	9.00*	*d*=0.48, *g*=0.47
20 (s)	4.60 ± 0.54	4.23	4.97	4.32 ± 0.63	3.90	4.74	6.09*	*d*=0.47, *g*=0.46
30 (s)	6.01 ± 0.60	5.61	6.41	5.73 ± 0.74	5.23	6.23	4.66*	*d*=0.42, *g*=0.40
IMTP (N)	773.59 ± 144.96	676.20	870.97	849.81 ± 198.60	716.39	983.23	9.85*	*d*=0.44, *g*=0.42
IMTP (kg/N)	14.25 ± 2.81	12.37	16.14	15.56 ± 3.02	13.54	17.59	9.19*	*d*=0.45, *g*=0.43
VJ (cm)	44.25 ± 6.16	40.11	48.39	47.06 ± 6.43	42.74	51.38	6.35*	*d*=0.44, *g*=0.43
BJ (cm)	1.82 ± 0.16	1.71	1.93	1.93 ± 0.17	1.82	2.04	6.04*	*d*=0.67, *g*=0.64

*P<0.05, **p<0.01, VT- vertical training group, Vo- theoretical velocity, Vmax- velocity max, *Fo*- Force, *Pmax*- Power max, IMTP- isometric midthigh pull, VJ- vertical jump, BJ- broad jump

Table 7.5: Means, % changes, confidence intervals (CI) and effect size (ES) pre and post-test across variables for HT group

Variables	HT (pre)	CI 95% (Lower)	CI 95% (Upper)	HT (post)	CI 95% (Lower)	CI 95% (Upper)	% Change	ES
***Vo* (m/s)**	6.67 ± 0.42	6.37	6.97	6.92 ± 0.58	6.51	7.33	3.74*	*d*=0.49, *g*=0.47
***Vmax* (m/s)**	6.40 ± 0.37	6.14	6.66	6.62 ± 0.42	6.32	6.93	3.44**	*d*=0.55, *g*=0.53
***Fo* (N)**	255.00 ± 53.45	216.77	293.23	327.60 ± 53.30	289.47	365.73	28.47**	*d*=1.36, *g*=1.30
***Pmax* (W)**	438.00 ± 93.22	371.32	504.68	529.20 ±106.96	452.69	605.71	20.82*	*d*=0.91, *g*=0.87
10 (s)	2.98 ± 0.32	2.75	3.21	2.67 ± 0.25	2.49	2.85	10.40**	*d*=1.08, *g*=1.03
20 (s)	4.51 ± 0.25	4.33	4.69	4.21 ± 0.21	4.06	4.36	6.65**	*d*=1.30, *g*=1.24
30 (s)	6.08 ± 0.37	5.81	6.35	5.74 ± 0.34	5.50	5.98	5.59**	*d*=0.96, *g*=0.92
IMTP (N)	774.40 ± 105.56	698.89	849.92	850.02 ± 81.99	791.37	908.67	9.76*	*d*=0.80, *g*=0.77
IMTP (kg/N)	14.41 ± 2.58	12.56	16.25	15.83 ± 3.10	13.61	18.05	9.85*	*d*=0.49, *g*=0.48
VJ (cm)	43.76 ± 2.90	41.69	45.83	46.57 ± 3.48	44.08	49.06	6.42*	*d*=0.88, *g*=0.84
BJ (cm)	1.81 ± 0.17	1.68	1.93	1.90 ± 0.15	1.79	2.01	4.97*	*d*=0.56, *g*=0.54

*P<0.05, **p<0.01, HT- horizontal training group, Vo- theoretical velocity, Vmax- velocity max, *Fo*- Force, *Pmax*- Power max, IMTP-isometric midthigh pull, VJ- vertical jump, BJ- broad jump

Table 7.6: Means, % changes, confidence intervals (CI) and effect size (ES) pre and post-test across variables for CON group

Variables	CON (pre)	CI 95% (Lower)	CI 95% (Upper)	CON (post)	CI 95% (Lower)	CI 95% (Upper)	% Change	ES
Vo (m/s)	6.68 ± 0.62	6.22	7.16	6.70 ± 0.40	6.39	7.01	0.30	*d*=0.04, *g*=0.04
Vmax (m/s)	6.41± 0.54	6.00	6.83	6.43 ± 0.37	6.15	6.72	0.31	*d*=0.04, *g*=0.04
Fo (N)	267.00 ± 45.25	232.22	301.78	272.56 ± 55.38	230.00	315.13	2.08	*d*=0.11, g=0.10
Pmax (W)	433.33 ± 90.28	363.94	502.73	423.78 ± 92.39	352.76	494.79	-2.20	*d*=0.10, *g*=0.10
10 (s)	2.86 ± 0.16	2.73	2.98	2.90 ± 0.15	2.78	3.02	-1.40	*d*=0.26, *g*=0.25
20 (s)	4.49 ± 0.24	4.31	4.67	4.48 ± 0.24	4.30	4.65	0.22	*d*=0.04, *g*=0.04
30 (s)	6.03 ± 0.35	5.76	6.30	6.04 ± 0.39	5.74	6.34	-0.17	*d*=0.03, *g*=0.03
IMTP (N)	726.00 ± 216.10	559.89	892.11	735.33± 194.82	585.58	885.08	1.29	*d*=0.05, *g*=0.04
IMTP (kg/N)	12.71 ± 4.12	9.55	15.87	12.81 ± 3.41	10.19	15.03	0.78	*d*=0.03, *g*=0.03
VJ (cm)	40.03 ± 6.09	35.34	44.71	40.06 ± 6.25	35.25	44.86	0.07	*d*=0.01, *g*=0.01
BJ (cm)	1.62 ± 0.22	1.45	1.78	1.61 ± 0.18	1.47	1.74	-0.62	*d*=0.05, *g*=0.05

CON- Control group, Vo- theoretical velocity, Vmax- velocity max, *Fo*- Force, *Pmax*- Power max, IMTP- isometric midthigh pull, VJ-vertical jump, BJ- broad jump

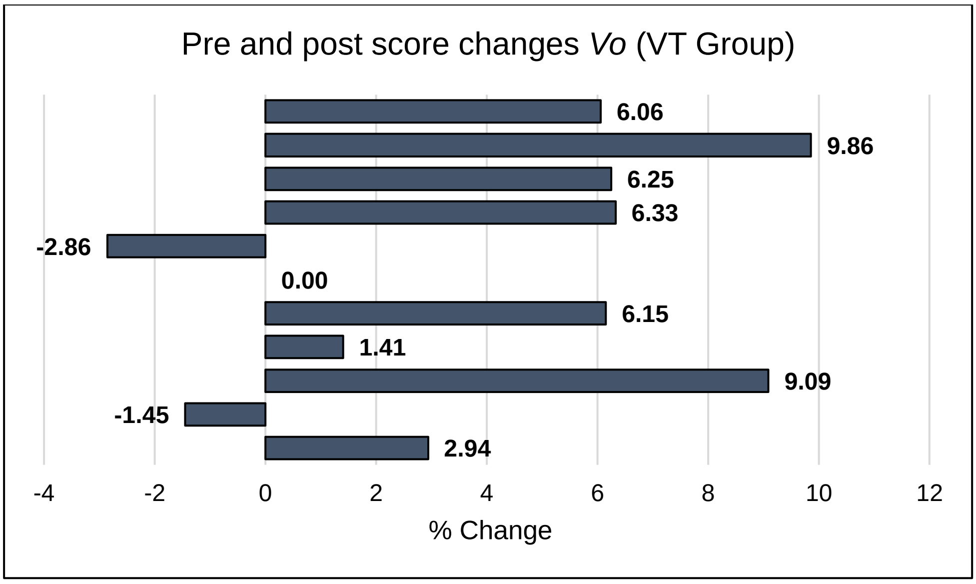

Figure 7.1: Individual Pre and post score % changes in *Vo* (VT Group)

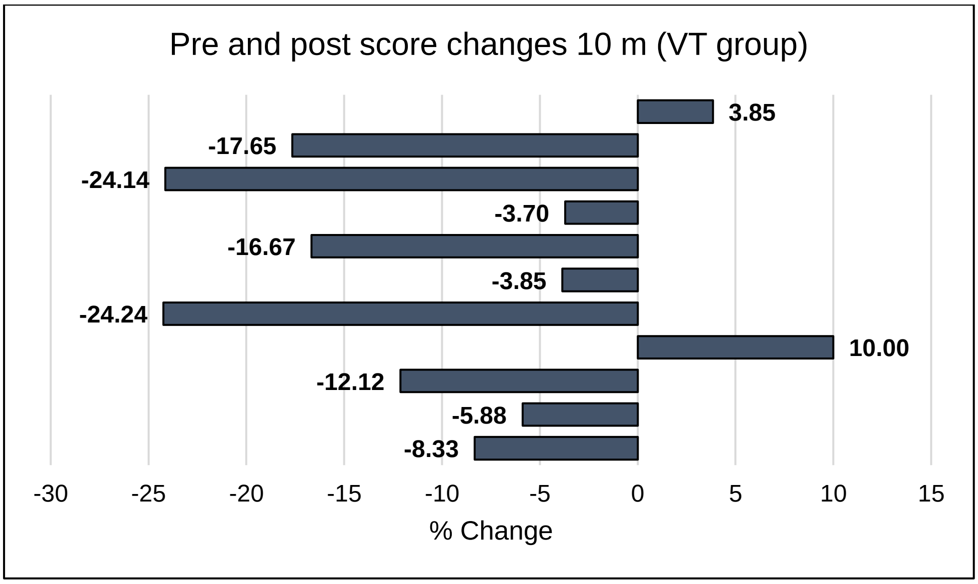

Figure 7.2: Individual Pre and post score % changes in 10 m (VT group)

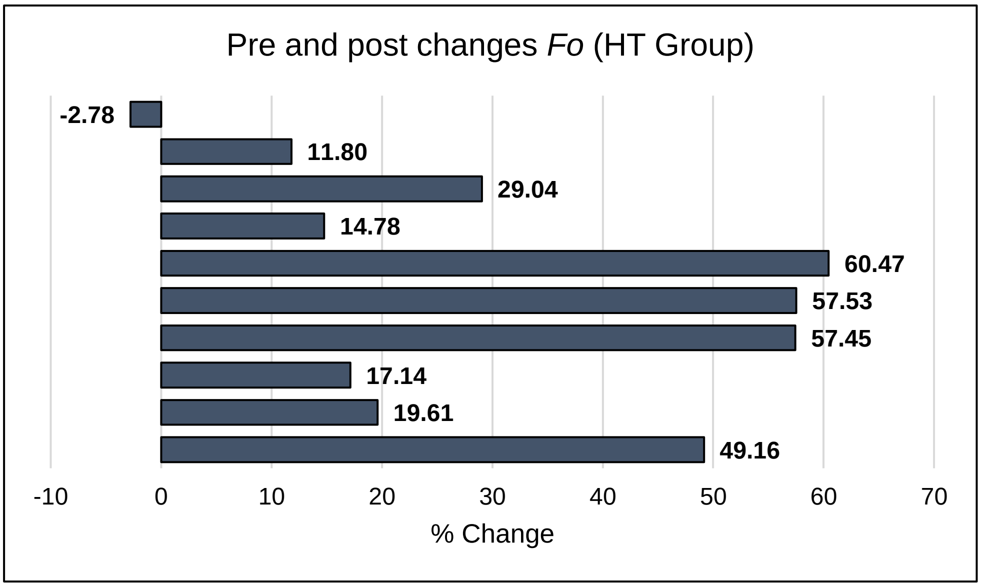

Figure 7.3: Individual Pre and post score % changes in *Fo* (HT group)

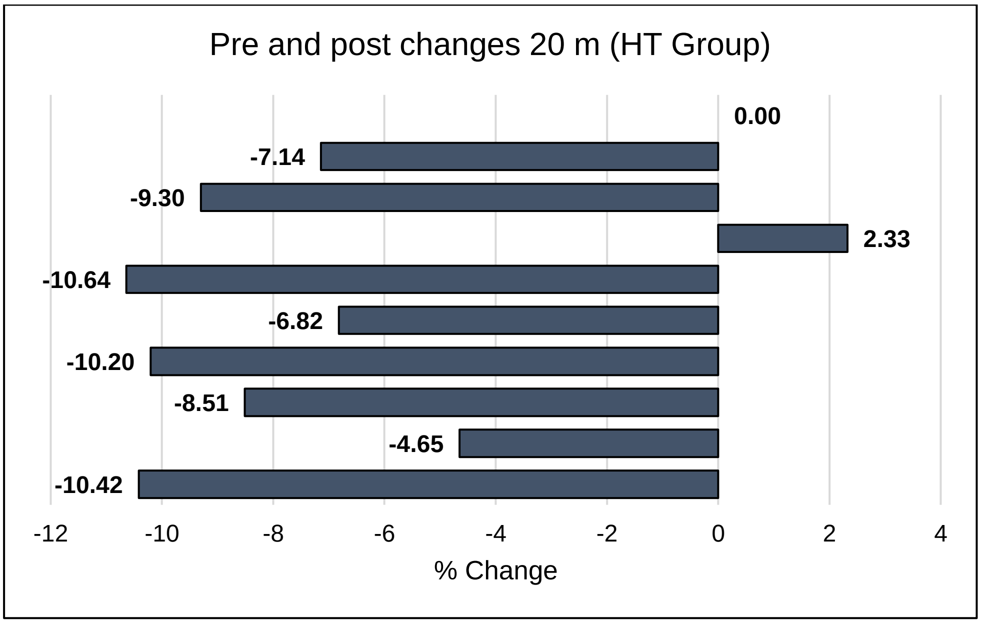

Figure 7.4: Individual Pre and post score % changes in 20 m (HT group)

Post hoc analysis showed that the VT group had significantly higher post scores compared to the CON group for *Vo*, *Vmax*, VJ, and BJ whereas the HT group had significantly higher post scores for 20 m split time and BJ compared to the CON group ($p<0.05$). There was no significant difference in post scores for any variable between the intervention groups. ANOVA results for between group differences are provided in Table 7.7.

Table 7.7: ANOVA results between group differences

Variables	Group differences
Vo post	F (2,27) =3.67, p=0.039
***Vmax* post**	F (2,27) =4.60, p=0.019
VJ post	F (2,27) =4.69, p=0.18
BJ post	F (2,27) =11.09, p= 0.00

Discussion

This study showed that, compared to a normal physical education class, post PHV girls were able to make significant improvements in speed, isometric strength, vertical and horizontal jump following 7 weeks of VT and HT training. With regards to sprinting kinetics, following VT, participants showed significant improvements in *Vo*, *Vmax*, 10, 20 and 30 m sprint time (ES: d=0.42, g=0.40 - d= 0.52, g= 0.50; $p<0.05$) but not *Fo* and *Pmax*. Following HT, participants significantly improved all sprinting variables with greater effects (ES: d= 0.49, g=0.47- d=1.36, g=1.30; $p<0.05$) than the VT group. There were no significant changes in the CON group across all variables. The findings indicate that both HT and VT can be effective for improving sprinting kinetics in female youth athletes. However, HT seems to be more effective in improving all sprinting kinetic variables.

More specifically, greater improvements were observed for all the split times following HT (10.40%, 6.65% and 5.59% for the 10, 20 and 30 m, respectively) compared to VT training. This finding supports previous research that investigated the effects of PT in young (u-13 and u 14) male basketball players (Gonzalo- Skok et al., 2019). Specifically, Gonzalo- Skok et al. (2019) showed significant changes in 5, 10, and 25 m (1.6-4.9%, ES=0.30-0.78) sprint time after 6-weeks of unilateral HT compared to bilateral VT (0.8-2.2%, ES = 0.13 to 0.28). In contrast, Yanci et al. (2016) reported trivial changes in 5 and 15 m sprinting speed (ES = 0.10-0.20) after 6 weeks of HT training in adult semi-professional soccer players. However, the participants in the Yanci et al. (2016) study were highly trained athletes compared to the lesser trained youth in the present study. There might be a larger scope of improvement with regards to sprinting performance in young lesser trained athletes compared to adult trained athletes. Therefore, based on the findings of the above studies it seems that HT may help to achieve greater improvement in sprinting kinetics due to force vector associated with sprinting motor pattern (Gonzalo-Skok et al., 2019). This study also supports a recent systematic review that reported HT to be the most effective way to enhance jump and sprint performance in young and adult males (Moran et al., 2020).

The findings from this study showed that VT improved sprint time to a greater extent over 10 m (9.00%) than 30 m (4.66%). This finding agrees with previous research that investigated the effectiveness of VT on sprinting performance in young male athletes (Ramirez-Campillo et al., 2015b). Ramirez-Campillo et al. (2015b) reported greater improvements in 15 m sprint time (3.5%, ES = 0.50) compared to 30 m sprit time (2.8%, ES = 0.30) in young soccer players after 6 weeks of PT that emphasized VJs. In young females, Bogdanis et al. (2019) showed positive changes in 10 and 20 m sprinting speed (9-10%) following 8 weeks of PT that predominantly included VJ training (p<0.01). Combined, this data suggests that VT may be useful in improving sprinting speed in young males and females.

The present study showed that *Vo* and *Vmax* improved significantly following both VT and HT (Tables 7.4 and 7.5). However, significant improvements in *Fo* and *Pmax* were only observed in the HT group (p<0.05). This finding may be the result of the dominant direction of force applied during the training intervention (Gonzalo-Skok et al., 2019). The importance of applying force in the horizontal direction could have positively influenced maximal velocity and power in this study due to motor pattern specificity (Morin, 2013). Since the direction of force in sprinting is predominantly in a horizontal plane (Stavridis et al., 2019). Therefore, greater improvements were seen in *Fo* and *Pmax* in the HT group compared to the VT group.

The VT group significantly improved both VJ and BJ scores in this study ($p<0.05$). This finding agrees with previous research that reported positive changes in counter movement jump and standing long jump after 8 weeks of PT that incorporated predominantly VT in young females (*d*= 0.67 and 1.57 respectively) (Bogdanis et al., 2019). In addition, both relative and absolute IMTP scores also significantly improved after VT in this study ($p<0.05$). Since VT group significantly improved non-sprint specific force and power measures (IMTP, VJ, and BJ) but not sprinting specific *Fo* and *Pmax*. Therefore, it can be assumed that changes in force and power involved in sprinting may be independent to IMTP, VJ and BJ due to force vector and motor pattern specificity in this population (Gonzalo-Skok et al., 2019).

Similarly, both VJ and BJ scores improved following HT in this study ($p<0.05$). A recent systematic review also reported that HT was as effective as VT in enhancing vertical performance in young and adult males (-0.04, $p=0.77$) (Moran et al., 2020). However, in adult male athletic (soccer) population, researchers have reported significant changes in horizontal jump performance after eight weeks of HT training with no meaningful changes in VJ performance ($p<0.01$) (Manouras et al., 2016). This could be because the participants in the Manouras et al. (2016) study were trained adults and might have required more specific VT to improve VJ performance compared to this study. In addition, both relative and absolute IMTP scores for HT group improved similarly compared to VT group (9.19-9.85%, $p<0.05$). Therefore, suggesting that HT can be effective in improving vertical, horizontal jump performance along with absolute and relative isometric strength in post PHV females.

The CON group in this study did not improve performance in any dependent variables with a substantial not significant decrease in *Pmax*, 10 m split time and BJ (-2.20, -1.40% and 0.62% respectively). Furthermore, the baseline mean scores for all the variables in the CON group were very similar to both the intervention groups. This could be because the CON group was significantly older (15.6 years) than both the intervention groups (13.5 and 13.6 years respectively) hence affecting force and velocity measures. However, there were no significant differences in the anthropometrical measures such as height and body mass between the CON group and the intervention groups. Therefore, suggesting that although natural development can improve speed and power measures, but this change could be further developed with specific progressive training in this cohort.

The ANOVA and post hoc analysis reported that post scores for the VT group were significantly higher in *Vo*, *Vmax* and VJ compared to the CON group ($p<0.05$). Whereas, 20 m split time in the HT group was significantly higher compared to the CON group post-training ($p<0.05$). In addition, both VT and HT group significantly improved BJ scores compared to the CON group**.** There were no significant differences between the VT and HT groups across all variables. This study supports previous research that reported significant changes in 20 m sprint speed and jumping performance in boys after 8 weeks of PT that included both HJ and VJ training compared to the CON group ($p<0.05$) (Fischetti et al., 2018). Therefore, PT programme that includes both vertical and horizontal jumping movements can improve sprinting kinetics, isometric strength and jump performance in post PHV female athletes compared to the conventional physical education class.

Conclusion

This study showed that both VT and HT can improve sprinting kinetics, isometric strength and jump performance in young female athletes. Moreover, sprinting performance is improved to a greater extent following HT, likely due to more specific motor patterns and direction of force involved. However, movements should be gradually progressed with regards to complexity, volume and intensity to avoid training related injuries. For example, jumps should be gradually progressed based on the eccentric demands, and foot contact per session. Future research should compare the effects of horizontal vs. vertical plyometric training in pre and mid PHV girls to inform any changes across maturation.

Chapter 8: Summary, Practical Applications, Limitations and Future Direction

Summary of the research

The purpose of this thesis was to better understand the effects of natural development and training on sprint kinetics, kinematics and speed in young female athletes. There is a paucity of research investigating kinetics, kinematics across maturation and the effects of ST and PT on sprinting speed in this cohort. Most researchers have investigated sprinting kinetics and kinematics and the effects of ST and PT in young males. However, due to the differences in growth and maturation between the gender, information related to young males is inadequate in understanding the kinetics and kinematics of sprinting speed and how young females adapt to ST and PT. Therefore, Chapter 2 provides a comprehensive review on the literature with regards to natural development of sprinting in young females. This includes a better understanding of factors that influence speed in this cohort such as growth, maturation, physiological differences between the genders, windows of opportunity for speed development, and changes in kinetics, and kinematics across maturation. Chapter 3 then provides a review on the effects of training (ST and PT) on sprinting performance in the youth population specifically young females. The review in chapter 3 pointed out that there were no previous studies that compared different forms of training such as ST vs. PT or HT vs. VT on sprinting speed in young females.

To assess the kinetics of sprinting speed in young females, a radar gun was incorporated in chapter 4. The radar gun is a valid and practically feasible tool to measure sprinting speed and kinetics among athletes (Simperingham et al., 2017). In addition, apart from sprint time, a radar gun provides more insight into sprinting variables including *Fo, Pmax, Vo, Vmax* that can help with the individualisation of training. However, its reliability in youth populations, particularly females, is unknown. Therefore, chapter 4 evaluated the reliability of sprinting kinetics in young females, including *Fo*, *Vo*, *Vmax*, *Pmax* and split times (0-30 m), was assessed using radar gun technology. Twenty-nine female athletes aged 13.70 $\pm$ 0.89 years (height = 1.62 $\pm$ 0.06 m; weight = 51.70 $\pm$ 8.41 kg) from a variety of different sports teams (hockey, football, netball, water polo) participated in the study. To assess intra-day reliability, two testing sessions including four 30 m sprints, separated by 7 days, were conducted. Inter-day reliability was also assessed using data from two of the sprints performed on the same day. The findings showed acceptable intra-day (ICC = 0.80-0.95; CV = 2.40-12.70%; and bias ranging from 0.65 to 1.65% across all variables) and inter-day (ICC = 0.74-0.98; CV = 1.70-11.20%; and bias ranging from 0.25-2.2% across all variables) reliability. These results suggest that measuring sprinting kinetics using a radar gun in young females is reliable.

When researching developing athletes, growth and maturation is an essential consideration. In fact, changes in biology associated with puberty affects how an individual performs physically. For instance, previous research has shown that the ability of a young athlete to sprint changes with the natural development of their kinetics and kinematics (Rumpf et al., 2015; Meyers et al., 2015; Meyers et al., 2017a). Unfortunately, prior to this thesis, most of the previous work in this area has been conducted with boys. Chapter 5, therefore, examined the kinetic and kinematic factors associated with sprinting in young females. More specifically, 11 mid-PHV (age = 12.70 $\pm$ 0.56, maturity offset = 0.58 $\pm$ 0.35) and 21 post-PHV (age = 13.53 $\pm$ 0.91; maturity offset = 1.82 $\pm$ 0.50) girls performed two 15 and 30 m sprints each. A number of sprinting kinetic and kinematic variables were captured using a radar gun and an Opto-jump. The results from this chapter showed that *Vo*, *Vmax,* step length, *Fo* and Pmax were significantly higher in post PHV girls ($p<0.05$). Univariate regression analysis reported that contact time, *Pmax*, step frequency, step length and leg length predicted sprint velocity (15 and 30 m) when maturity was controlled with contact time being the strongest predictor of all. The findings of this study provide insight into the natural development of sprinting in young females and will help practitioners specifically develop training programmes that can effectively improve sprinting kinetics and kinematics.

When reviewing the literature, it was found that both ST and PT were useful in improving sprinting speed in the young females (Siegler et al., 2003, Myer et al., 2005; Hopper et al., 2017; Bogdanis et al., 2019; Hammami et al.,2019; Chaabene et al., 2019; Gonzalez-Garcia et al., 2019). However, no study to date compared the two training methods on sprinting performance in girls. Therefore, chapter 6 investigated the effects of ST and PT on sprinting performance, along with isometric strength and unilateral horizontal jumps. This chapter also compared the two training methods (ST vs. PT) on sprint kinetics.

To investigate these two questions, fifty-two young females were recruited for a 7-week training study. The participants were randomly assigned to one of two groups; ST (n = 16, age = 13.36 $\pm$ 0.84, maturity offset = 1.31 $\pm$ 0.82) and PT (n = 21, age = 13.38 $\pm$ 0.75; maturity offset = 1.33 $\pm$ 0.73). The CON group consisted of physical education students (n=15, age = 13.95 $\pm$ 0.54, maturity offset = 1.71 $\pm$ 0.64), and tested for sprinting kinetics, isometric strength and unilateral horizontal jump distance before and after the intervention. The ST group significantly improved 10 m split time (6.76%; *d*=0.66, *g*=0.65) and *Fo* (16.36%; *d*=0.67, *g*=0.65) whereas the PT group significantly improved *Vmax* (4.91%; *d*=0.51, *g*=0.50), *Fo* (11.12%; *d*=0.40, *g*=0.40) and *Pmax* (7.88%; *d*=0.26, *g*=0.26). The CON group had a significant decrement in sprinting times (0-30 m) and kinetics variables such as *Fo* and *Pmax* ($p<0.05$). When the groups were compared, it was found that both the intervention groups had significantly higher post scores for *Vmax*, 10, 20, 30 split times and single jump scores on both sides compared to the CON group with no differences between the intervention groups. The findings of this study suggest that both ST and PT training can improve sprinting kinetics, jumping performance and isometric strength in young female athletes compared to regular physical education activity. Moreover, based on the findings of this chapter it would appear that ST is more useful for improving the first 10 m of a sprint. This is likely due to greater force required to overcome inertia at the start of a sprint. Alternatively, PT may be more useful for improving *Vmax* due to better use of SSC at the later stage of a sprint when more momentum is gained.

Chapter 6 revealed that PT per se can positively influence maximal velocity in young females. This thesis then looked to expand on this knowledge by comparing how different forms of plyometric training affect sprinting speed in the same cohort. Specifically, chapter 7 investigated the effectiveness of HT and VT on sprinting speed and compared the two with regards to their effectiveness on sprinting speed. Given these training modalities are commonly used in practice, comparing their effectiveness was warranted. Participants were randomly divided into two groups and trained for 7 weeks, twice a week; VT (n = 11, age = 13.50 ± 0.96, maturity offset = 1.60 ± 1.14) and HT (n = 10, age = 13.40 ± 0.92, maturity offset = 1.60 ± 0.93). The CON group consisted of physical education students (n = 9, age = 15.60 ± 0.31, maturity offset = 2.90 ± 0.55). Participants were tested for sprinting kinetics i.e. *Fo*, *Pmax*, *Vo*, *Vmax*, 10, 20 and 30 m split times using a radar gun over 30 m, isometric strength**,** VJ height and HJ distance before and after the intervention. Both HT and VT groups significantly improved all variables of interest ($p<0.05$). With regards to sprinting, the VT group significantly improved all kinetic variables except *Fo* and *Pmax* (*d*=0.42*, g*=0.40 to *d*=0.52*, g*=0.50). The HT group in comparison improved all sprint kinetic variables with a greater ES (*d*=0.49, *g*=0.47 to *d*=1.36, *g*=1.30). There were no changes in the sprinting performance in the CON group. In comparison to the CON group, the VT group significantly improved *Vo, Vmax*, VJ and BJ scores whereas HT group significantly improved BJ and 20 m split time scores ($p<0.05$). There were no significant differences between the intervention groups. The findings of this study suggest that both VT and HT can improve sprinting kinetics, jumping performance and isometric strength in young females. Due to force vector, HT may be more useful in improving sprinting performance compared to VT. Therefore, training programmes to improve sprinting performance in young females should include both HT and VT with a specific emphasis on HT.

In summary, a radar gun is a reliable piece of equipment to measure sprinting kinetics in young female athletes. Kinetic variables such as *Vmax* (15m) *Vo* (30 m)*, Fo, Pmax* along with step length seem to be significantly greater in post PHV girls compared to mid PHV girls. Decreasing ground contact time, increasing step length, step frequency and *Pmax* can positively influence maximal velocity in mid and post PHV females. Moreover, ST, VT and HT can all improve sprinting kinetics in post PHV female athletes. However, ST might be useful for the first 10 m of the sprint to overcome inertia and HT training has the biggest effect on sprinting kinetics overall. Therefore, practitioners should use a combination of these training methods with an emphasis on HT training to improve sprinting speed in post PHV females.

Practical Applications

Based on the findings of this thesis, the following practical applications may be helpful for coaches, teachers and researchers working with young females:

1. Radar gun technology is reliable for the assessment of sprinting kinetics in young females. It can provide specific information on sprinting performance such as *Fo, Pmax, Vo, Vmax,* and split times in young females. This can be helpful for practitioners in individualisation of training based on the information collected.
2. The kinetics (i.e., *Pmax, Fo, Vo*) and kinematics (i.e., step length) of sprinting differ between mid and post PHV females. Accordingly, where possible, assessment of these factors will support the individualisation of training and likely result in better performance outcomes.
3. Contact time, *Pmax,* step frequency, step length and leg length were found to predict maximal velocity in mid and post PHV girls, with contact time being the strongest predictor of them all. Therefore, mid and post PHV girls can benefit from PT that can improve lower extremity tendon stiffness and rate of force development in a horizontal plane thus reducing ground contact time during sprinting.
4. The force vector is an important factor to consider in overall ST and PT programme for young females. ST and PT that has a horizontal force vector may have a better transfer to sprinting speed in post-PHV girls.
5. ST may be more useful in the initial part of the sprinting to overcome greater inertia by producing greater force at the start. However, ST may not be very useful to improve maximal velocity and distances beyond first 10 m of a sprint. PT on the other hand may be more useful in improving maximal power and velocity. Therefore, a combination of ST and PT can be valuable in improving sprinting kinetics. Both ST and PT should incorporate movements that include both vertical and horizontal force vectors and the load should be carefully progressed based on technical competency of the individual. Chapter 9 provides comprehensive practical suggestions for practitioners based on the findings of chapter 6.
6. Both HT and VT were found to be effective means of training to improve sprinting speed. However, only HT was effective in improving all sprinting variables. Therefore, a PT plan that includes both HT and VT with a specific emphasis on HT

should be included for developing sprinting speed. In addition, both HT and VT should be progressively developed based on individual competency. Chapter 9 provides comprehensive practical suggestions for practitioners based on the findings of chapter 7.

Limitations

There were several limitations of the thesis, due in part to the unique integration within a school curriculum and limitations with the equipment.

1. Sprinting assessment in this thesis was performed from a static starting position. However, in many sports, sprints are also performed when the athlete is already moving. Moreover, variability can exist when static starts are used with young athletes who lack the strength to effectively propel their body forward. This can result in an athlete rising too early, causing variability in force production particularly in the initial phase of the sprint.
2. No pre PHV participants were used in Chapter 5. Previous studies in boys have reported greater kinetic and kinematic changes between pre and mid PHV groups compared to mid to post PHV due to changes in growth and maturation (Meyers et al., 2015; Meyers et al., 2017a; Rumpf et al., 2015). Therefore, not having access to pre PHV girls in this study is another limitation of this thesis.
3. The Opto-jump used to assess sprinting kinematics in chapter 5 allowed measurement up to only 15 m and required the testing to be done indoors due to set up logistics. Therefore, not able to assess full 30 m and conduct the assessment outdoors is considered as one of the limitations of this thesis as there could be changes in kinematics beyond the first 15 m of a sprint.
4. The standard error for Mirwald et al. (2002) equation has been reported to be 0.57 years in girls (Koziel & Malina, 2018). This error could have influenced the allocation of participants with regards to maturation categories in chapter 5.
5. In Chapter 6, the number of participants per group was uneven. A minimum attendance of two sessions per week, for 7-weeks, was required for inclusion in the data analysis. Unfortunately, 4 participants in the ST group did not meet this requirement. In addition, 5 participants from the CON group were not available for

post testing. Therefore, the PT group had more participants in comparison to ST and CON making the groups unequal.

6. The total number of participants in this study was limited (n=30) in Chapter 7. This was because participants in the training groups were recruited from Athlete Pathway Programme (APP) from year 8-10. The number of participants varied throughout the year based on selection, academic commitments, sporting competitions and outdoor education programmes, particularly in year 10. Therefore, there was limited access to the APP students that reflected the total participants in the intervention groups (n=21). In addition, the CON group participants were recruited from regular physical education classes. However, year 9 and 10 physical education students were not available to participate in this study due to school commitments. Hence, the CON group participants consisted of year 11 students and were older than the intervention groups even though there was no significant difference in anthropometry and baseline performance between the intervention groups and the CON group as reported in chapter 7.

Future Research Directions

Significant growth-related changes occur between the pre and mid PHV phases in youth. Therefore, future research investigating the kinetics and kinematics of sprinting speed in young females should include a pre PHV group. With regards to kinematics, equipment that allows assessment of speed beyond the distance of 15 m should be incorporated to provide a better understanding of how variables such as step length, frequency, flight time, and contact time changes after the initial acceleration phase of a sprint across maturation. Once an athlete gains momentum and moves towards top speed the mechanics tend to shift from the initial phase of the sprint due to change in the angle of the body position. Therefore, this shift in mechanics may provide more information regarding changes in the kinematics across maturation.

Future research on the effects of ST and PT on sprinting speed should consider force velocity profiling across pre, mid and post PHV females and prescribe ST or PT based on the force velocity assessment. This could help practitioners working with young females provide specific training plans to improve sprinting performance. Furthermore, future research should include both rolling and static start sprinting since sprinting from a rolling start is commonly seen in many sports. Also, kinetics and kinematics associated with rolling starts may differ to static starts due to the need to overcome greater inertia during static starts.

Chapter 9: Practical Applications: Strength and plyometric training to improve sprinting speed in young females

This section discusses the implementation of ST and PT in young females to enhance sprinting speed based on the findings of this thesis in chapters 6, 7, and the review of the literature in chapters 2 and 3. The influence of growth and maturation, individual movement competency, force vectors and planes of motion will also be discussed with regards to ST and PT (Malina et al., 2004; Lloyd et al., 2015).

Strength Training

Many forms of ST have been used to enhance sprinting speed in youth (Siegler et al., 2003; Lloyd et al., 2016a; Rumpf et al., 2012; Uthoff et al., 2019). More specifically, free weight movements that allow effective force production through the kinetic chain, such as squat and deadlift variations, have been preferred (Escamilla et al., 2002). In addition, because specificity is critical for maximising the benefits of speed and power training in youth (Faigenbaum et al., 2009), resisted sprint training using sleds has recently become popular (Petrakos, Morin, & Egan, 2016). Resisted sprint training helps improve an athlete's ability to apply propulsive force more effectively, particularly during the acceleration phase of sprinting (Kawamori et al., 2014).

Upper body and trunk movements should not be ignored in programme design for overall speed development in young females. A strong and stable trunk provides a foundation for the torques generated by the limbs and can contribute to efficient locomotion (Thorstensson et al., 1984). Specifically, trunk movements that resist excessive lumbar rotation and extension during explosive limb movements can be useful for better proximal to distal kinetic chain transfer during sprinting (Kibler, Press, & Sciascia, 2006). In chapter 7, anti-lumbar extension trunk movement was incorporated in both HT and VT programmes that reported significant improvements in sprinting performance across groups ($p<0.05$). Both closed and open chain upper body movements, such as a push-up, suspension row and unilateral upper body press and pull can also be valuable to develop shoulder flexors and extensors involved in sprinting due to the importance of arm drive (Mann, 1981; Macadam et al., 2018) In addition, a RAMP (raise, activate, mobilise and potentiate) based warm-up that elevates body temperature with low intensity activities, activates and mobilises key muscle groups and joints, and increases potentiation through activities that improve subsequent performance should be performed prior to ST (Jeffreys, 2007). Therefore, a training programme that includes lower and upper body strength training, sprint specific resisted training (e.g. sled push), and trunk movements that resist excessive extension and rotation at the lumbar region preceded by RAMP warm up would be useful in developing sprinting speed in young females.

Growth, maturity and movement competency

In chapter 6, It was found that ST that included upper and lower body movements over 7 weeks improved *Fo* and 10 m split times in post PHV girls. Given the benefit of ST in adolescent females on sprinting performance previously (Gonzalez-Garcia et al., 2019), it can be speculated that ST can be useful during and post puberty to improve force-generating capacity and power to weight ratio, as body mass tends to increase considerably in girls compared to their male counterparts. Furthermore, to optimise the benefits of ST during puberty, it is important to provide a foundation in ST before reaching puberty. Therefore, exposing pre PHV and approaching PHV girls to basic multi-joint bodyweight strength movements such as squats, push-ups, split squats, suspension rows/ chin-ups may be beneficial.

Regardless of the type of ST implemented, load and complexity of movement should be gradually progressed over time. It can be challenging for a growing adolescent female athlete with limited ST experience and an unfavourable limb to torso ratio to execute a conventional back squat during which the load is away from the centre of mass (Gullet et al., 2009). Therefore, utilising squatting variations where the load is closer to the centre of mass, such as a goblet squat (incorporated in chapter 6) or a trap bar deadlift, may be safer and more effective (Figure 9.1) (Gullet et al., 2009; Braidot et al., 2007). Once movement competency is achieved, more complex movements can be utilized to challenge coordination (Dahab & McCambridge, 2009). The load can be progressed every week by 10-20% over 8 weeks for the lower body. Previous researchers have successfully increased lower body load by 10-30% over 7 weeks to improve sprinting speed (10 and 20 m) in adolescent female soccer players without previous ST experience (Gonzalez-Garcia et al., 2019).

Figure 9.1: Goblet squat with heel lift for an athlete with ankle limitations

In addition, due to change in weight to power ratio during puberty certain movements may be challenging for the girls (Malina et al., 2004; Viru et al., 1999). Therefore, the right progressions/regressions should be incorporated to gradually build movement competency. For example, if a mid-PHV female athlete is unable to perform a push up with a good technique (i.e. without dropping the head/hips and elbows bent minimum 90 degrees) then a regression should be incorporated such as band-assisted push up that assists during the concentric phase of the movement (Figure 9.2).

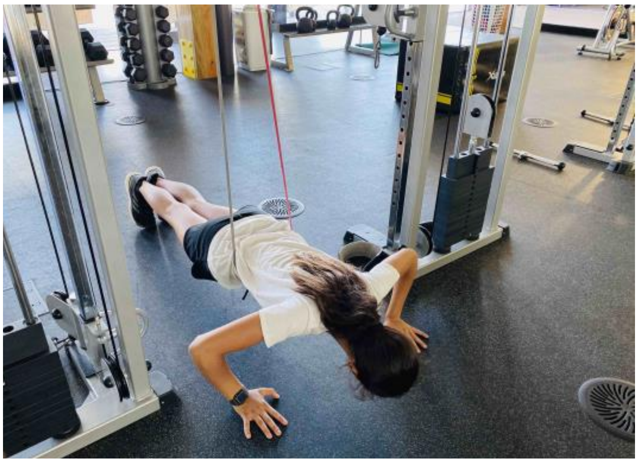

Figure 9.2: Push Up with assistance to allow optimal technique

Force vectors and planes of motion

Training using a combination of horizontal, vertical, unilateral and bilateral movements that allow athletes to produce force across vectors and develop coordination in multiple planes of motion may help athletes propel their body at higher velocities and with greater efficiency (Contreras et al., 2017; Gonzalo-Skok, et al., 2017; Morin et al., 2017). For example, 6-8 weeks intervention that included horizontal strength training improved sprinting performance over 10 and 20 m in adolescent male and female athletes respectively (Contreras et al., 2017; Gonzalez-Garcia et al., 2019). In addition, unilateral strength training has been reported to show meaningful improvements (5 m: ES= 0.37 $\pm$ 0.41; 20 m: ES = 0.31$\pm$ 0.31) in 5 and 20 m sprinting performance respectively after 9 and 12 weeks in trained adult rugby academy players (Appleby, Cormack, & Newton, 2020). Therefore, ST programmes that include unilateral and split stance exercises (Figure 9.3) and movements in the horizontal plane would seem beneficial.

Figure 9.3: Split squat

Table 9.1 provides an example of a ST programme to develop sprinting speed in young female athletes. It includes 2 sessions a week over two 4-week phases. The first phase emphasises technical competency and progressions for each movement are provided. Most of these movements have been successfully incorporated in Chapter 6. In Chapter 6, ST over 7 weeks was found to improve *Fo* and 10 m split times specifically in post PHV girls.

Table 9.1: 8-week strength training programme

Exercises	Reps	Sets	Rest	Progressions
Sled March (horizontal lower body sprint specific strength)	Phase 1- 10 m Phase 2- 20 m	Phase 1- 3 Phase 2- 5	Phase 1- 60-90s Phase 2- 90-120s	Loaded push (10-20%, high velocity)
Goblet Squats (vertical lower body)	Phase 1- 8 Phase 2- 5	Phase 1- 3 Phase 2- 5	Phase 1- 60-90s Phase 2- 90-120s	Trap bar (increase load 10-20%)
Push Up / Cable unilateral push (upper body push- shoulder flexors)	Phase 1- 8 Phase 2- 5	Phase 1- 3 Phase 2- 5	Phase 1- 60-90s Phase 2- 90-120s	Feet elevated/ loaded (5-10%)
Suspension row/ one arm cable pull (upper body pull- shoulder extensors)	Phase 1- 8 Phase 2- 5	Phase 1- 3 Phase 2- 5	Phase 1- 60-90s Phase 2- 90-120s	Feet elevated/loaded (5-10%)
Split Squat (unilateral lower body)	Phase 1- 8 Phase 2- 5	Phase 1- 3 Phase 2- 5	Phase 1- 60-90s Phase 2- 90-120s	Rear feet elevated/loaded (10-20%)
Abdominal roll outs (lumbar anti-extension trunk stability)	Phase 1- 8 Phase 2- 10	Phase 1- 3 Phase 2- 4	60s	Smaller size object/longer lever arm
Hip raise (horizontal lower body)	Phase 1- 8 Phase 2- 5	Phase 1- 3 Phase 2- 5	Phase 1- 60-90s Phase 2- 90-120s	Unilateral/loaded (10-20%)

Plyometric training

A PT programme to enhance sprinting speed should include horizontal, vertical, bilateral and unilateral movements (Gonzalo-Skok et al., 2019; Ramirez-Campillo et al., 2015a). The total volume of work should be gradually progressed over time and the intensity of the exercises should be based on individual competency (Gonzalo-Skok et al., 2019). For example, an athlete incompetent at repeated speed bounding and/or countermovement jumps should focus on controlled landing mechanics during a single jump first. In addition, other forms of power training should also be included for overall development for sprinting. Incorporating medicine balls can be useful to develop upper body power, eliminate end range deceleration and allow athletes to express themselves better without the concern of controlling the load (Stockbugger & Haennel, 2001). Upper body movements such as medicine ball throw, and slams can help develop shoulder flexors and extensors in an explosive manner seen in sprinting. However, the load of the balls should be appropriate without compromising technique and velocity.

Growth, maturity and movement competency

Similar to ST, growth and maturity play an important role in PT design. The heightened neural drive prior to PHV phase can provide a great opportunity to introduce PT (Lloyd et al., 2016a; Rumpf et al., 2012). Studies have also reported the benefits of PT in sprinting speed in post PHV girls (Hopper et al., 2017; Myer et al., 2005) However, lack of coordination can negatively impact plyometric movements. Hence, movements should be gradually progressed based on individual competency. For example, bilateral hopping should be introduced prior to unilateral versions so that a lack of coordination does not negatively impact movement quality and velocity.

Force vectors and planes of motion

PT should include movements that have both horizontal and vertical force vectors to improve propulsion in sprinting (Gonzalo-Skok et al., 2019). Horizontal and VJs such as countermovement jumps, BJs, hurdle jumps, and drop jumps can be very beneficial if progressed gradually (see figure 9.4 and 9.5) (Lloyd et al., 2016a). Similarly, unilateral plyometric movements that require stabilization in multiple planes, such as hops and bounds, should also be included in overall PT.

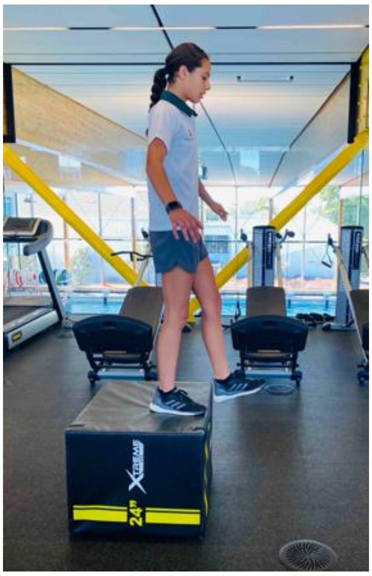

Figure 9.4: Drop jump

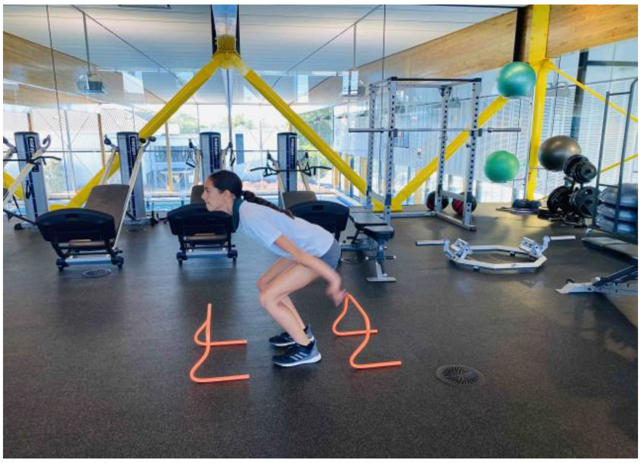

Figure 9.5: Hurdle jump and stick

Similar to ST, a RAMP based warm-up that involves multi-directional runs, dynamic stretching/activation (hips, ankle, spine, shoulders) and variations of skipping drills such as A Skips (horizontal single leg skipping) that encourages the triple extension of (hips, knees & ankles) and low ground contact time can be useful in priming the central nervous system and increasing potentiation before starting PT (Jeffreys & Moody, 2016). The first phase should emphasize technical competency and intensity should be gradually built in the next phase. Table 9.2 provides PT recommendations for young female athletes. Most of these movements have been successfully incorporated in chapter 6 and 7. PT particularly with a horizontal emphasis has been reported to improve *Vmax, Vo, Fo, Pmax,* 10, 20, & 30 m split times in post PHV female athletes in chapter 7. Similar to the ST programme, the complexity and intensity should increase in phase 2 (after 4 weeks). Progressions for each movement is provided in table 9.2.

Table 9.2: 8-week plyometric training programme

Exercises	Reps	Sets	Rest	Progressions
Drop jump progression (reactive vertical jump)	5	Phase 1- 3 Phase 2- 5	Phase 1- 60-90s Phase 2- 90-120s	Increase height based on landing competency
Medicine ball chest throws (upper body horizontal)	8	Phase 1- 3 Phase 2- 5	Phase 1- 60-90s Phase 2- 90-120s	Increase weight
Counter movement jumps (vertical jump)	5	Phase 1- 3 Phase 2- 5	Phase 1- 60-90s Phase 2- 90-120s	Repeated (multiple response- low ground contact time)
MB slams (vertical upper body)	8	Phase 1- 3 Phase 2- 5	Phase 1- 60-90s Phase 2- 90-120s	Increase weight
Bound land and stick (horizontal unilateral)	5 each	Phase 1- 3 Phase 2- 5	Phase 1- 60-90s Phase 2- 90-120s	Repeated (multiple response- low ground contact time)
Hurdle jumps (horizontal)	5	Phase 1- 3 Phase 2- 5	Phase 1- 60-90s Phase 2- 90-120s	Unilateral/repeated (multiple response- low ground contact time)

The importance of having fun

Motivating young females to adhere to a structured ST can be challenging. In certain cases, this may be due to the stereotypical perceptions of ST with regards to the social construct of a female body (Zach & Adiv, 2016). Therefore, creating an environment that encourages an enjoyable experience is essential. Research shows that semi-structured play and movement exploration can be used for this purpose, see figure 9.6 and 9.7 (Barreiro & Howard, 2017). Indeed, Larson et al. (2014) found semi-structured recess to be useful in increasing step count and physical activity duration in children. Accordingly, a traditional warm-up RAMP protocol combined with games and movement exploration that precedes the ST programme could be very beneficial (Jeffreys & Moody, 2016). Movement exploration activities have been successfully incorporated in both the interventions in chapters 6 and 7. Furthermore, alternating lower, upper and trunk exercises within the session in a form of a circuit training can be helpful to avoid muscular fatigue and increase enjoyment in this cohort (McEntyre, 2018).

Figure 9.6: Movement exploration: Monkey bar

Figure 9.7: Movement exploration: Cone and tennis ball balance

Table 9.3 and 9.4 provides combined ST and PT programmes with a specific emphasis on ST in table 9.4 and PT in table 9.5 respectively.

Table 9.3: Phase 1: Combined strength and plyometric training (Strength emphasis)

Exercises	Reps	Sets	Rest	Progressions
1a. Mini hurdle jump and stick	5	3	60s	Repeated jumps (SSC-low ground contact time)/ Unilateral
1b. Medicine ball chest throw hip drive (kneeling)	8	3	60s	No hip drive
2a. Goblet Squats	8	3	60s	Trap bar (increase resistance 10-20%)
2b. Unilateral upper body press	8	3	60s	Increase resistance (5-10%)
3a. Sled push	10m	3	60s	Increase resistance (10-20% BW) and velocity
3b. Unilateral upper body pull	8	3	60s	Increase load
4a. Hip raise	8	3	60s	Feet elevated/ loaded/ unilateral (10-20%)
4b. Abdominal Rollout (anti- lumbar extension)	8	3	60s	Smaller object (longer lever arm)

*SSC- stretch shortening cycle

Table 9.4: Phase 2: Combined strength and plyometric training (Plyometric emphasis)

Exercises	Reps	Sets	Rest	Progressions/regressions
1a. Drop and stick	5	5	90s	Drop jump (height based on competency)
1b. Medicine ball slams	5	5	90s	Increase load gradually
2a. Single leg bound and stick	5	5	90s	Repeated bounds (multiple response SSC- low ground contact time)
2b. Split stance Medicine ball chest throw	5	5	90s	Increase load
3a. Rear feet elevated split squat	5	4	90s	Increase load (10-20%)
3b. Feet elevated suspension row	5	4	90s	Loaded (5-10%)
4a. Unilateral hip raise	8	3	60s	Feet elevated/ loaded/ unilateral (10-20%)
4b. Quadruped opposite arm and leg movement (anti-lumbar rotation)	8	3	60s	Cable chop (anti lumbar rotation with load)

*SSC- stretch shortening cycle

Conclusion: Putting it all together

Based on the findings in chapter 6 and 7 and previous research, it is clear that ST and PT can improve sprinting speed in young females (Myer et al., 2005; Siegler et al.., 2003; Hopper et al., 2017). However, a gradual progression of load and complexity of movement over time is important. Furthermore, growth, movement competency, force vectors and planes of motion should be considered in planning ST and PT for young females. For example, pre PHV girls can benefit more from a training plan that emphasises plyometrics training due to the heightened neural adaptation during this phase of growth, but fundamental bodyweight ST should not be ignored.

If fundamental bodyweight ST is taken care of during the pre PHV phase, then it is relatively easier to add complexity and load at a later stage (mid and post PHV phase). For example, loading a squatting pattern to develop lower body strength is much easier when movement competency using bodyweight is optimal. Similarly, during the mid and post PHV phase, emphasis on ST training will be important due to the accelerated growth phase where bones develop faster than muscles, but PT should still continue to progress. ST can help increase muscle size, that can result in better force production during sprinting whereas, PT can help in increasing tendon stiffness, and reduce ground contact time. Therefore, training programme that include a combination of ST and PT with a specific emphasis on PT for pre PHV girls and ST for mid and post PHV girls may be useful in improving sprinting performance in young females.

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Appendix A. Ethics Approval

TE WĀNANGA ARONUI
O TĀMAKI MAKAU RAU

Auckland University of Technology Ethics Committee (AUTEC)

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

7 March 2019

Craig Harrison
Faculty of Health and Environmental Sciences

Dear Craig

Re Ethics Application: **19/26 The effects of strength and power training on speed in youth female athletes**

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 7 March 2022.

Non-Standard Conditions of Approval

1. Review the parent information sheet for appropriate us of the first and third person.

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

Standard Conditions of Approval

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

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

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

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

Yours sincerely,

K O'Connor

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

Cc: , kaushik.talukdar21@gmail.com; Michael McGuigan

Appendix B (1). Participation Information Sheet

Participant Information Sheet

Athlete Development Programme

Date Information Sheet Produced: 24/01/19

Project Title

The effects of strength and power training on speed in youth female athletes.

An Invitation

Hello, I am Kaushik Talukdar I am a PhD student at AUT as well as the Strength and Conditioning Manager at St Cuthbert's College and I would like to invite you to participate in this study. Participation in this research is entirely voluntary and you are able to withdraw from the study at any time. Your involvement in this study will not impact your selection into future sports teams or classes at St Cuthbert's College. This research is being done as part of my PhD and I want to find out how I can optimise your sprint performance to enhance your athletic potential. Will you help?

What is the purpose of this research?

Sprint speed plays an important role in sports performance in youth. For instance, being at the right place at the right time to receive a pass in soccer, hockey and netball. To date, research has shown changes in sprint kinetics and kinematics across maturation and supported the role of strength and power development in optimising sprint speed in youth. However, most research investigating sprint speed in youth has looked at boys. There is currently no research investigating sprint kinetics and kinematics across maturation in young females. In addition, limited research exists investigating the role of strength and power on sprint speed in young girls.

The information gained from this research will be presented in a way so that your name and contact details will remain confidential. The information from this research will be anonymous when presented at an international sports science conference, submitted to a sports science journal for publishing, and when included in my PhD thesis.

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

You are identified as a potential participant for this research as you fit into the following categories:

- Between 9 and 15 years of age
- You play a sport that requires you to sprint
- You are injury free for the last 6 months and/or are fully participating in training and competition for sports

How do I agree to participate in this research?

You will receive this document with an attached Assent and Consent Form. If you would like to participate in this study your guardian will need to fill out and sign a Guardian Consent Form (see attached) and you will need to fill out and sign an Assent Form (see attached).

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

What will happen in this research?

The primary objectives of this thesis are: a) to investigate the kinetics and kinematics of sprint speed in young girls (9-15 years) across maturation, including horizontal and vertical forces and step length, contact time and step frequency, and b) to optimize sprint speed in this population. Specifically, strength and power training interventions will be investigated. Strength training intervention will include split squat and power interventions with horizontal and vertical jump progressions each performed twice a week. The interventions will be 8 weeks and data (sprint speed, strength -isometric midthigh pull, horizontal and vertical jump) will be collected pre and post interventions. The findings from this research will help optimise sprint speed in young females.

What are the discomforts and risks?

It is not anticipated that you will experience discomfort that would be greater than that occurring in a normal physical education and strength and conditioning class.

You will be exposed to a small amount of physical risk of injury as you will be performing some resistance training, jump training and sprinting. However, if there happens to be any injuries such as sprains, strains, wounds, dislocation and fractures then participants will be entitled to no fault cover under ACC. Information provided here https://www.acc.co.nz/im-injured/injuries-we-cover/what-we-cover/?smooth-scroll=content-after-navs

How will these discomforts and risks be alleviated?

Risk will be reduced as much as possible by implementing a suitable warm-up and cool-down before and after each testing session, abstaining from high intensity training in the 24 hours prior to each testing occasion, and arriving to each testing session well hydrated and having eaten at least 90 minutes prior to the start. You will also be sufficiently familiarized with all physical movements and tests.

What are the benefits?

The benefits for you being a part of this study include:

- Being made aware of your potential risk for injury
- Being made aware of your ability to warm up, accelerate, sprint, lift, and jump

The findings of the proposed research will be valuable for sport coaches and athletes as well as adolescent athletic development coaches, teachers and researchers.

Finally, this research will benefit myself, as this study will be included in my PhD thesis and I will gain skills in coaching, teaching and collecting data.

How will my privacy be protected?

All of the data from this study will be de-identified. That means that your name or contact information will not be available outside of the research database. The data from this research will be made available for approved researchers without any additional consent beyond that given by yourself or guardian. I will keep all of your data confidential and any data published or used for presentations will be anonymous. However, the dual role of being the strength and conditioning manager and the researcher will ensure limited confidentiality.

What are the costs of participating in this research?

Since this research will be during curriculum time, no additional time will be needed. However, some data collection days may require additional time outside of curriculum. This will be done at either before/after school hours or lunch time to not interrupt any other classes.

What opportunity do I have to consider this invitation?

You have 2 weeks to decide whether or not you would like to participate in this study.

Will I receive feedback on the results of this research?

You will receive feedback and a summary of your results at the end of the data collection. If you would like any additional information, please contact myself.

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

Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor, Dr Craig Harrison

Email: craig@athletedevelopment.org.nz

Phone: + 64 27 2265181

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

Whom do I contact for further information about this research?

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

Researcher Contact Details:

Kaushik Talukdar

kaushik.talukdar@stcuthberts.school.nz

Phone: +6421-0451469

Project Supervisor Contact Details:

Dr Craig Harrison

Email: craig@athletedevelopment.org.nz

Phone: *+ 64 27 2265181*

Approved by the Auckland University of Technology Ethics Committee on *type the date final ethics approval was granted*, AUTEC Reference number *type the reference number*.

Appendix B (2). Consent form

Parent/Guardian Consent Form

Project title: ***The effects of strength and power training on speed in youth female athletes.***

Project Supervisor: ***Dr Craig Harrison***

Researcher: ***Kaushik Talukdar***

- ○ I have read and understood the information provided about this research project in the Information Sheet dated dd mmmm yyyy.
- ○ I have had an opportunity to ask questions and to have them answered.
- ○ I understand that my child taking part in this study is voluntary (their choice) and that I may withdraw my child/children from the study at any time without being disadvantaged in any way.
- ○ I understand that if I withdraw my child/children from the study then I will be offered the choice between having any data that is identifiable as belonging to my child/children removed or allowing it to continue to be used. However, once the findings have been produced, removal of our data may not be possible.
- ○ My child is not suffering from any illness or injury that impairs her physical performance.
- ○ I agree to my child/children taking part in this research.
- ○ I agree that my child will participate in sprint, power and strength training and testing
- ○ Although I might agree for my child to participate I accept that they have the right to decline participation.
- ○ I wish to receive a summary of the research findings (please tick one): Yes○ No○

Child/children's name/s : ....

....

Parent/Guardian's signature: ....

Parent/Guardian's name: ....

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

....

....

....

....

Date:

***Approved by the Auckland University of Technology Ethics Committee on** type the date on which the final approval was granted **AUTEC Reference number** type the AUTEC reference number*

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

Appendix B (3). Assent form

TE WĀNANGA ARONUI O TĀMAKI MAKAU RAU

Assent Form

Project title: ***The effects of strength and power training on speed in youth female athletes.***

Project Supervisor: ***Dr Craig Harrison***

Researcher: ***Kaushik Talukdar***

- ○ I have read and understood the sheet telling me what will happen in this study and why it is important.
- ○ I have been able to ask questions and to have them answered.
- ○ I understand that I can stop being part of this study whenever I want and that it is perfectly ok for me to do this.
- ○ If I stop being part of the study, I understand that then I will be offered the choice between having any information that that other people can know is about me removed or letting the researcher keep using it. I also understand that sometimes, if the results of the research have been written, some information about me may not be able to be removed.
- ○ I am not suffering from any illness or injury that impairs my physical performance.
- ○ I agree to take part in this research.
- ○ I agree that I will participate in sprint, power and strength testing and training
- ○ I wish to receive a summary of the research findings (please tick one): Yes○ No○

Participant's signature: ....

Participant's name: ....

Participant Contact Details (if appropriate):

....

....

....

....

Date:

***Approved by the Auckland University of Technology Ethics Committee on** type the date on which the final approval was granted **AUTEC Reference number** type the AUTEC reference number*

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