An investigation into the impact of coaching strategies with respect to physical and performance characteristics of male youth of varying biological maturation.

By

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Certificate of Attestation

I, Regan Standing, certify that all experimental work, results, analyses and conclusions reported in this Master's thesis are entirely my own effort except were otherwise acknowledged. I also certify that the work is original and has not been submitted for any other award.

May, 2019

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CHAPTER 1: AN INVESTIGATION INTO THE IMPACT OF COACHING STRATEGIES WITH RESPECT TO PHYSICAL AND PERFORMANCE CHARACTERISTICS OF MALE YOUTH OF VARYING BIOLOGICAL MATURATION

Introduction

With an ever-increasing focus on elite sporting success, research has continued to investigate strategies to best achieve this outcome in a time and energy efficient manner. One branch of this research has spread into youth sport and proposes insight into how coaches and trainers can best equip young individuals to succeed in a performance context, but also achieve sporting longevity (Ford et al., 2011; Lloyd & Oliver, 2012; Lloyd, et al., 2015). These pursuits have generated widely accepted strategies such as the 'long term athlete development (LTAD)' concept expressed by Lloyd and Oliver (2012), who discuss the need to target biological 'training windows' to maximise learning and adaptation within specific biomotor qualities. This model also stresses the need for late specialisation and encourages the exploration of various sporting and movement-based concepts, which may ultimately lead to not only better performance, but longevity in the sport (Lloyd, Oliver, et al., 2015).

Interwoven within the LTAD model is the need to understand the influence of biological maturation and the effects the adolescent growth spurt has on functional, physical and neural factors associated with exercise (Ford et al., 2011; Lloyd et al., 2009). Due to the highly individual nature regarding the timing and intensity of the adolescent growth spurt, understanding the mechanisms, adaptations and corresponding impact these have is critical if effective training is the desired outcome. Current research has identified anthropometric differences between varying levels of biological maturation including height, seated height, weight and limb length (Murtagh et al., 2017), as well as various neurological factors (De Bellis, 2001; Huttenlocher, 1979; Yakovlev & LeCours, 1967). These variables have been linked to adaptations in performance outcomes (Ford et al., 2011; Meyers, 2016), but in some cases this also corresponds with a heightened injury risk (Cane, Maffulli, & Caine, 2008; Kemper et al., 2015; Van Der Sluis, Elferink-Gemser, Brink, & Visscher, 2015; Van Der Sluis et al., 2014).

Other research has investigated the influence of biological maturation on training interventions including plyometrics (Lloyd, Radnor, De Ste Croix, Cronin, & Oliver, 2016;

Meyers, Oliver, Hughes, Lloyd, & Cronin, 2015; Rumpf, Cronin, Pinder, Oliver, & Hughes, 2012) and resistance training (Lloyd, Radnor, De Ste Croix, Cronin, & Oliver, 2015; Rodriguez-Rosell et al., 2015), which have provided insight into the types of training that are most beneficial for each level of maturation. Many of these studies have used sprinting and jump-based activities to measure intervention effectiveness (Asadi, Ramirez-Campillo, Arazi, & Sáez de Villarreal, 2018; Lloyd, Radnor, et al., 2015; Meyers et al., 2015; Rumpf et al., 2012), perhaps due to the closed nature of the skills, the application of these movements to multiple sports, and/or the ease of testing.

One aspect of training that has not been investigated in depth is the influence of coaching methods, despite the acknowledged differences in neural factors (De Bellis, 2001; Huttenlocher, 1979; Yakovlev & LeCours, 1967), which may provide unique learning characteristics within maturation levels (Asadi et al., 2018; Lloyd, Radnor, et al., 2015; Meyers et al., 2015; Rumpf et al., 2012). Past literature has discussed how various focus, engagement, feedback, and delivery strategies can influence participant success and performance in motor tasks (Bunker & Thorpe, 1982; den Duyn, 1997; Duran, 2016; Kidman 2005; Porter, Wu & Partridge, 2010), but there are limited studies investigating the timing of these strategies in relation to PHV. By further investigating the differences in physical and performance-based characteristics (Chapter 2), researchers can begin to understand how a coach or trainer can best interact with individuals of varying biological maturation, to optimise learning uptake and maximise training gains (Chapter 3). The significance of this study is that it would begin to fill a gap within current maturational youth literature into ‘how’ to coach, to support the current findings of ‘what’ to coach.

Thesis overview

Thesis structure

This thesis will be presented as two standalone experimental chapters which will culminate in a thesis discussion linking the two papers under the overarching concept of maturation in male youth. Chapter 2 is currently under review in ‘Cogent Medicine’, and the intention of Chapter 2 is to identify physical, injury and performance-based differences between maturational groups within a general school-based population of youth. These observed differences within Chapter 2 will then inform the methodology and coaching strategies utilised within Chapter 3, which will investigate the effectiveness of various coaching methods in order to maximise adaptation, motor ability and injury prevention within each maturational group. The outcome of this thesis hopes to inform practitioners as to how they can best implement their training programmes to maximise learning and adaptation across a range of biological maturation levels. Rather than just knowing when training should occur which has been investigated previously, it is hoped this thesis will provide insight into how coaching should occur to maximise learning within this diverse adolescent population. Due to the layout of this thesis with the individual papers, there is an element of content repetition throughout Chapters 1,2,3 and 4 which needs to be acknowledged, although the various contexts provides uniqueness throughout.

Thesis purpose

The purpose of this thesis is to identify and describe both physical, and performance-based differences between maturational groups within a general population of youth. This will provide critical insight into where these individual differences lie and inform strategies to best implement subsequent interventions. Secondly, this thesis aims to critique and contrast various coaching strategies and their effectiveness in improving sprint and jump performance within varying levels of biological maturation, whilst also assessing their impact on the risk of injury. These findings will aid coaches and practitioners in their unique applied environments and inform as to how they can influence learning, and the application of this learning, more-so than just through the programmes they write, but how they then implement these with their specific population of individuals.

This thesis includes two chapters addressing the pre-mentioned purpose of this study: Chapter 2: The influence of maturation on functional performance and injury markers in male youth.

Chapter 3: The effectiveness of progressive and traditional coaching strategies to improve sprint and jump performance across varying levels of maturation within a general youth population.

CHAPTER 2: THE INFLUENCE OF MATURATION ON FUNCTIONAL PERFORMANCE AND INJURY MARKERS IN MALE YOUTH

Abstract:
Maturation of youth throughout adolescence has shown to have corresponding effects on physical and neuromuscular characteristics, which vary between individuals' due to inherited genetic traits. The aim of this study was to identify the influence of maturation on sprinting and jump performances, whilst quantifying injury markers in 95 youth males (age 13.2 - 15.7y). Comparative statistics were performed between maturation groups, identifying significant differences ($p<0.05$) in all measured anthropometric variables. Sprint and jump performances were positively influenced (*trivial* to *large* effect sizes) by maturation status, whereas injury markers revealed no significant differences between groups. Increases in limb length, muscle size and muscular force output due to corresponding neuromuscular maturation, may help account for these improvements. Individuals' within the circa PHV group exhibit a larger variability in sprint and jump performance when compared to the pre or post PHV groups. This variability may be attributed to the under-researched phenomenon of 'adolescent awkwardness'. To conclude, performance characteristics of youth at the same chronological age vary considerably based on biological maturation, which may have consequences for long-term athlete development.

Introduction

During the adolescent growth phase, it is common to see variability within a variety of physical characteristics such as height, weight, and limb length when comparing individuals', even those from a similar population or ethnicity (Mirwald, Baxter-Jones, Bailey, & Beunen, 2002; Philippaerts et al., 2006). These variations can be tentatively measured by quantifying the individual's level of biological maturity, also known as their biological age (Meyers, Oliver, Hughes, Lloyd, & Cronin, 2017; Sherar, Esliger, Baxter-Jones, & Tremblay, 2007; Van Der Sluis et al., 2014). Age at peak height velocity (PHV) is a term used to describe the period where the maximum rate of growth occurs during the adolescent growth spurt. By calculating time to, or from PHV, it is possible to provide a non-invasive quantitative estimate of an individual's level of biological maturation (Philippaerts et al., 2006; Van Der Sluis et al., 2014). The timing and intensity of this PHV period differs between individuals' and is genetically determined by a wide range of inherited variables (Mao et al., 2013; Sovio et al., 2009). Research has shown that as an individual enters their adolescent growth spurt, there are often resultant implications for their motor control and coordination (Rhodri S. Lloyd et al., 2015). The term 'adolescent awkwardness' has been used to describe this phenomenon, which is caused by an increase in bone length, typically within the trunk and limbs, prior to the corresponding muscular growth (Van Der Sluis et al., 2014). This occurrence is accompanied by an imbalance between strength and flexibility, which also increases the risk of both structural and soft tissue injuries (Hägglund & Waldén, 2016; Van Der Sluis et al., 2014). Despite these physiological fluctuations in coordination and growth, some literature suggests this does not correspond with a decrease in performance in activities requiring high force outputs or multiple segment sequencing such as sprinting and jumping (Rhodri S. Lloyd et al., 2015).

Sprinting is an activity that is present in a variety of youth sporting activities, and is underpinned by several key kinetic and kinematic determinants (Hunter, Marshall, & McNair, 2004a). Aspects such as ground reaction force (GRF) (Kawamori, Nosaka, & Newton, 2013), contact time, flight time (J. Cronin & Hansen, 2006), step length, and step frequency (Meyers, 2016) have been shown to strongly impact sprint performance. These variables are directly influenced by discrete physiological attributes such as strength, power and flexibility (Cavagna & Franzetti, 1986; Franzetti & Heglund, 1988; Perrier, Pavol, & Hoffman, 2011). Both Murtagh et al., (2017), and Meyers (2016), suggest jump performance is similarly influenced by muscle size, motor unit activation and force output, as well as the discrete physical characteristics of the individual. As physical growth and neural maturation occurs during the adolescent growth phase, the determining factors of sprinting and jumping may be positively influenced, suggesting those of the same chronological age will likely vary in ability depending on their own level of biological maturation (Meyers, 2016).

Due to the current lack of depth in findings within this area, the aim of this study was to identify the influence of PHV on maximal sprint and unilateral jump performance, whilst assessing the corresponding markers of injury in a school-based male youth setting, as opposed to an athletically driven cohort which has frequently been utilized within relevant literature. Variability of individual responses within each maturation group was sought, in an attempt to identify 'adolescent awkwardness'. Based on the findings of Meyers et al., (2017) and Philippaerts et al., (2006) it is hypothesised that increases in height, seated height, and weight will be evident as maturation increases. These physical characteristics will lead to improvements in performance variables, with a higher occurrence of injury markers and variability during the circa period of PHV, as per the suggestions of Hägglund & Waldén (2016), and Van Der Sluis et al., (2014).

Methods

Study design

This study utilised a cross-sectional study design to compare descriptive data from three distinct representative groups within the targeted male youth population. Comparative groups were allocated post testing with the use of a sex-specific PHV calculation (Mirwald et al., 2002) which utilises height, seated height and limb length, to measure maturation offset (pre < -0.50 y, circa -0.49 y to +0.49 y, post> +0.5 y) (Meyers et al., 2017). Despite this equation having a reported error of ± 0.592 y (Meyers et al., 2017), the allocations were made in accordance with similar studies (Meyers, 2016; Meyers et al., 2017), and to allow better distribution across maturation groups within this population.

Participants

A total of 95 youth males (age 13.2 - 15.7 y; maturity offset -1.0 to 2.6 y) from a general schooling population volunteered for this study. There were no performance or sporting pre-requisites for this study, as a representation of general youth ability was sought. Participants were required to demonstrate their suitability via a completed health questionnaire (with no contraindications present) and guardian consent. Ethical approval was granted for all procedures from the Waikato Institute of Technology human ethics research group (see Appendix 1).

Experimental procedures / Data collection

Participants were required to attend one single testing session lasting approximately one hour within an indoor gym facility. All tests were performed in bare feet whilst wearing appropriate active-wear. A standardised warm up was undertaken prior to the session, which lasted approximately 12 min and consisted of dynamic, progressive exercises targeting the whole body initially, then the lower limbs specifically. Familiarisation occurred prior to the commencement of each test via verbal instruction and a visual demonstration. Each participant was provided the opportunity to practice each movement prior to the recorded trials.

Anthropometrics

Height, seated height and weight were measured on testing day to provide information for the PHV calculation (Mirwald et al., 2002). Standing height was measured via a free-standing stadiometer, with participants feet shoulder width apart and the chin and line of sight parallel to the floor. The headpiece was lowered firmly on the centre of the participants head whilst they were standing with erect posture. Seated height was measured whilst sitting on a 40cm box placed against a wall with a tape measure aligned vertically from centre of the box. Participants had their legs together and hands rested on their knees. The lower back was firmly against the wall at the rear of the box and the chin and eye line were parallel to the floor. The headpiece was lowered firmly on to the participants head, ensuring a right angle was kept with the wall. Both standing and seated heights were measured to the nearest millimetre. Weight was taken on a set of electronic scales which were zeroed prior to each participants measurement.

Maximal sprint tests

Participants performed three maximal effort 20m sprints (2 min rest between each trial), utilising a standing split stance with their preferred foot placed on the starting line 0.5m back from first timing light (White & Gunter, 2002). A dual-beam-modulated SWIFT timing light system (Wacol, Australia), captured performance times using four sets of lights placed at the zero, 5m, 10m and 20m marks, at a height of 0.85m (to top of tripod), with the lane width approximately 3m. The initial set of timing lights was set lower (65cm to the top of tripod) than the other tripods to account for the likely hunched start positions of the participants. Each trial began with a forward movement of the torso, as opposed to a rocking motion where momentum could be generated prior to first foot movement. Once instructed to step up to the line, the participant was free to commence the trial in their own time to remove any variability in reaction times. Similar protocols have been deemed to have a high level of reliability by previous literature, with coefficient of variation values ranging from 1.9-2.6% and intra-class correlation coefficients (ICC) of 0.89 – 0.95 (Moir, Button, Glaister, & Stone, 2004).

Unilateral horizontal jump

Maximal unilateral horizontal jump performance was obtained via three jumps for distance from each leg (take-off one leg and land with two), with approximately 2 min rest between trials (alternating legs each trial). Measurements were taken from the rear-most heel on a successful landing. An unsuccessful landing consisted of an individual falling backwards, stepping backwards, or putting their hands down behind the rear-most heel (these trials were repeated). Hands were free to move throughout the movement and no coaching or technical cues were given. Similar protocols for this test have identified that the horizontal jump is a reliable test with ICC values greater than 0.85.

Tuck jump assessment

A single 10s bilateral tuck jump (TJ) assessment was performed and qualitatively marked against a modified rubric (Table 1) (Fort-Vanmeerhaeghe et al., 2017), which provides measures of quadricep dominance, trunk dominance, leg dominance, ligament dominance, feedforward mechanisms and neuromuscular fatigue.. Intra-rater reliability statistics (ICC) for the modified TJ assessment was calculated at 0.971 (substantial) and a 93% PEA, with Kappa scores ranging from 0.615 to 1.00 ($p<0.05$) for each of the 10 individual variables within the rubric. On the gym surface where the test was to be performed, tape was used to create a box with edges 41cm in length and 35cm wide, which the participants were instructed to remain on if possible (Fort-Vanmeerhaeghe et al., 2017). This assessment required the participant to perform continuous tuck jumps for a period of 10s within the specified area (if possible). Instructional cues consisted of the following; "bring knees to chest", "continuous jumps for 10s", "jump as high as you feel comfortable". Two high-speed cameras (Casio Exilim, ex-zr200) capturing at 120fps on fixed tripods (set at 0.8m to base of tripod) provided frontal and sagittal views of the participant during their tuck jump assessment. Scores were allocated via post-session video analysis and compared against a severity based kinematic marking criteria (Table 1).

Table 1: Modified TJ rubric derived from Fort-Vanmeerhaeghe et al., (2017).

Phase of jump	Criterion	View	None (0)	Small (1)	Large (2)
Knee and thigh motion	1. Lower Extremity valgus at landing	F	No valgus	Slight Valgus	Obvious valgus: Both knees touch
	2. Thighs do not reach parallel (peak of jump)	L	The knees are higher or at the same level as the hips	The middle of the knees are at a lower level than the middle of the hips	The whole knees are under the entire hips
	3. Thighs not equal side to-side during flight	F	Thighs equal side to side	Thighs slightly unequal side to side	Thighs completely unequal side to side (one knee over the other)
Foot position during landing	4. Foot placement not shoulder width apart	F	Foot placement exactly shoulder width apart	Foot placement less than shoulder width but more than one foot width of one another	Foot placement less than one foot width of one another
	5. Foot placement not parallel (front to back)	L	Foot placement parallel (end of feet within big toe length)	Foot placement unparalleled (end of feet greater than big toe length, but less than half their foot)	Foot placement obviously unparalleled (end of feet greater than half their foot length)
	6. Foot contact timing not equal (Asymmetrical landing)	F	Foot contact timing equal side-to-side	Foot contact timing slightly unequal	Foot contact timing completely unequal
	7. Excessive landing contact noise	F / L	Subtle noise at landing (landing on balls of feet)	Audible noise at landing (heels touch ground during landing but controlled)	Loud and pronounced noise at landing (entire foot and heel touch ground during landing with lack of control)
Plyometric ability	8. Pause between jumps	F / L	Reactive and reflex jumps	Small pause between jumps	Large pause between jumps or double contact between jumps
	9. Technique declines prior ten seconds	F / L	No decline in technique	Decline in technique after five secs	Decline in technique before five seconds
	10. Does not land in same foot print (Consistent point of landing)	F / L	Touches tape with both feet	One foot on tape, one foot not touching tape	Both feet miss tape

Note: F = Frontal view; L = Lateral view

Statistical analysis
The two best individual sprint and jump trials were averaged for each participant and used as their comparative score, as per the recommendations of Maulder, Bradshaw, and Keogh (2008). A one-way ANOVA with Bonferroni post hoc test was used to assess between group differences in sprint times, jump performance and tuck jump scores (SPSS Version 22, IBM, Armonk, NY). Cohens effect sizes and percentage differences with 90% confidence limits were calculated between maturation status and performance variables with qualitative inferences used to describe effect magnitudes (Hopkins, 2002), with *p*-values ($p<0.05$) were used to indicate significance.

Results

Anthropometric data revealed significant differences (p<0.05) in all measured variables (height, seated height and weight) between maturation groups (see Table 2).

Table 2: Anthropometric variables compared between maturation groups

Variable	Pre PHV (N = 11) Mean ± SD	Circa PHV (N = 38) Mean ± SD	Post PHV (N = 46) Mean ± SD
Age (y)	13.7 ± 0.3	14.1 ± 0.6	14.7 ± 0.5
Age at PHV (y)	14.5 ± 0.4	14.1 ± 0.6	13.5 ± 0.5
Maturity offset (y)	-0.7 ± 0.2	0.0 ± 0.2	1.3 ± 0.5
Height (cm)	157.6± 7.0	163.6 ± 5.4*	172.7 ± 5.9*#
Seated Height (cm)	81.3 ± 3.8	84.1 ± 2.2*	90.6 ± 3.4*#
Weight (kg)	46.9 ± 4.4	54.0 ± 8.4*	64.2 ± 9.3*#

Note: * = significant difference to pre (p<0.05); # = significant difference to circa (p<0.05)

Significant group differences (p<0.01) revealed increased maturation status positively influenced sprint performances. The circa group displayed faster sprint times (0.1%, 0.7% and 1.8%) than the pre group over 5m, 10m and 20m distances, respectively (see Table 3). Significantly faster (p<0.01) mean sprint times were demonstrated by the post group over all distances in comparison to both circa and pre groups (see figure 1), with statistics inferring *small* to *large* effect sizes (see Table 3).

Dominant (HJD) and non-dominant (HJND) horizontal jump tests demonstrated greater jump performance with increased maturation. The circa group had mean jump distances 3.5% and 3.7% larger than pre groups (ES = 0.29-0.30), when comparing respective dominant and non-dominant legs (see Table 2). Post groups revealed greater dominant and non-dominant jump distances (1.67m ± 0.22; 1.61m ± 0.22) in comparison to the circa group (1.62m ± 0.22; ±; 1.54m ± 0.22), with comparative statistics inferring *trivial* to *moderate* effect sizes (see Table 3). Post group had significantly further jump distances ($p<0.01$) than pre group in the HJD (see figure 2).

Tuck jump total scores (TJS) identified no significant differences between pre (12.8 ± 2.0), circa (12.5 ± 2.6) or post (12.3 ± 3.3) group means. Effect sizes of 0.25 – 0.83 depict *small* to *moderate* statistical differences between groups (see Table 3). There were no significant differences between any specific injury markers when group comparisons were made.

Table 3: **Comparative statistics between maturation groups and performance variables**

Metric	Comparative statistic	Post vs Pre	Post vs Circa	Circa vs Pre
5m	%Diff ± CL	-4.3 ± 2.5	-4.2 ± 2.4	-0.1 ± 2.8
	p value	0.005*	0.004*	0.960
	ES, ± CL	-0.84, ± 0.47	-0.66, ± 0.37	-0.01, ± 0.47
	Inference	*large-small*	*moderate-small*	*unclear*
10m	%Diff ± CL	-5.4 ± 2.6	-4.7 ± 2.7	-0.7 ± 3.0
	p value	0.001*	0.004*	0.706
	ES, ± CL	-1.00, ± 0.47	-0.67, ± 0.37	-0.10, ± 0.47
	Inference	*large-small*	*moderate-small*	*unclear*
20m	%Diff ± CL	-6.4 ± 3.3	-4.7 ± 2.9	-1.8 ± 3.6
	p value	0.002*	0.005*	0.399
	ES, ± CL	-1.00, ± 0.49	-0.63, ± 0.37	-0.25, ± 0.50
	Inference	*large-small*	*moderate-small*	*unclear*
HJD	%Diff ± CL	10.2 ± 5.8	3.5 ± 5.1	3.5 ± 6.2
	p value	0.007*	0.263	0.332
	ES, ± CL	0.83, ± 0.48	0.25, ± 0.37	0.29, ± 0.49
	Inference	*small-large*	*trivial-moderate*	*unclear*
HJND	%Diff ± CL	6 ± 5.9	4.6 ± 5.4	3.7 ± 6.1
	p value	0.095	0.160	0.312
	ES, ± CL	0.48, ± 0.47	0.31, ± 0.36	0.30, ± 0.50
	Inference	*trivial-moderate*	*trivial-moderate*	*trivial-moderate*
TJS	%Diff ± CL	-6.7 ± 10.3	-3.1 ± 9.6	-3.7 ± 9.9
	p value	0.243	0.571	0.506
	ES, ± CL	-0.30, ± 0.43	-0.12, ± 0.36	-0.19, ± 0.49
	Inference	*moderate-trivial*	*unclear*	*unclear*

Note: CL = 90% confidence limit; ES = effect size; HJD = Horizontal jump dominant leg; HJND = Horizontal jump non-dominant leg; TJS = Tuck jump total score; * = significant difference (p<0.01).

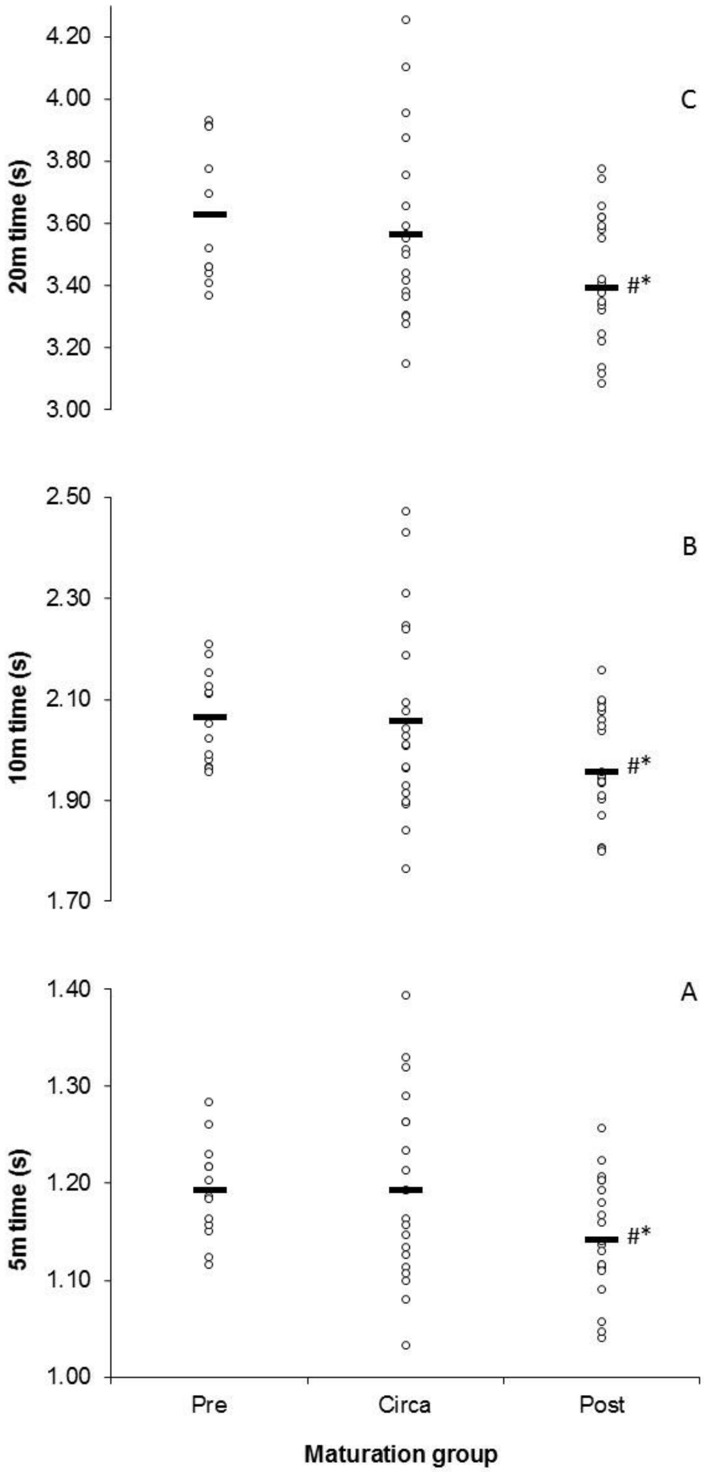

Figure 1: 5m, 10m, and 20m individual sprint times across maturation groups.
Note: A = 5m times; B = 10m times; C = 20m times; # = significant difference to pre; * = significant difference to circa.

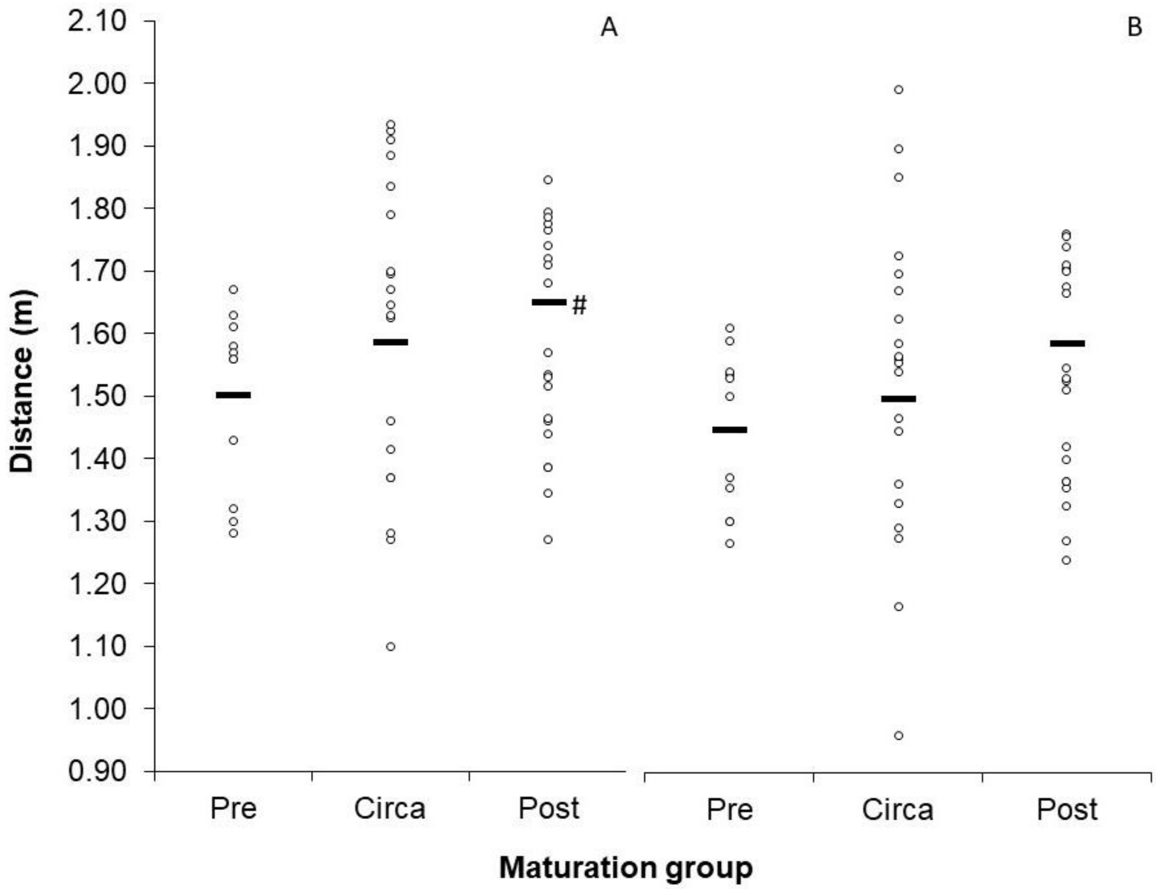

Figure 2: Mean horizontal jump performance on dominant and non-dominant legs across maturation groups.
Note: Figure 2A = HJD; Figure 2B = HJND; # = significantly different to pre

Discussion

The purpose of this study was to identify the influence of maturation on maximal sprinting, jumping performances and injury markers in adolescent males. Current findings from literature within this field led to the hypothesis that; as maturation occurred, increases in physical characteristics such as height, seated height, and weight would be evident within the population; these findings would also be coupled with corresponding improvements in sprint and jump performance. Secondly, markers of injury and increased performance variability would be most prevalent within the circa stage of maturation due to the rapid onset of physical growth and the associated neurological changes. Results of this study partially supported these hypotheses, with anthropometric and performance variables demonstrating comparable findings to previous literature (Asadi, Ramirez-Campillo, Arazi, & Sáez de Villarreal, 2018; Meyers et al., 2017) whereas injury marker data revealed dissimilar trends to those originally hypothesised.

Anthropometric testing of height, seated height and weight, displayed significantly different values between maturation groups (see Table 2), which supports both the hypothesis of this study and previous literature investigating this concept (Meyers et al., 2017; Murtagh et al., 2017). The adolescent growth phase is characterised by an alteration in hormonal activity, namely with increases in androgens such as testosterone, growth hormone and thyroid hormone (Ford et al., 2011). Increases in these androgen concentrations aid the facilitation of growth in muscular length and cross-sectional area, as well as differential bone growth throughout the appendicular limbs and trunk (Ford et al., 2011; Meyers, 2016; Van Der Sluis et al., 2014). The concomitant mass that accompanies this growth can be detrimental to performance and / or the underlying mechanisms related to performance (Meyers et al., 2017); although it is believed that the associated increases in physical size may also negate these potential decrements (Meyers, 2016; Meyers, Oliver, Hughes, Lloyd, & Cronin, 2017).

Articles by Meyers (2016), and Meyers et al., (2017), discuss how alterations in anthropometric measures (including standing height and limb length) and the corresponding body tissues may elicit improvements in motor activities such as sprinting. These findings were supported by the current study, where mean sprint times at 5m, 10m and 20m improved as biological maturation (and anthropometric measures) increased (see figure 1). Lower limb length aids in increasing step length (Meyers, 2016), as well as decreasing ground contact time in some populations (Lloyd et al., 2016a), consequently improving sprint performance if other variables such as step frequency and flight time are not detrimentally altered in the process (Hunter et al., 2004a). The larger percentage increases observed in the circa to post transition, compared to the pre to circa stage, are likely due to the increases in muscular strength and force output of individuals' as they mature physically post PHV (Ford et al., 2011; Meyers, 2016; Van Der Sluis et al., 2014). The elevated testosterone and growth hormone levels allow for greater muscular development, therefore increasing the potential force and power output which are vital for early sprint speed success (Spinks, Murphy, Spinks, & Lockie, 2007). Despite comparable performance trends to current literature, the underlying kinematic mechanisms could not be confirmed in this study as the measuring of such variables was outside the intended scope.

Similarly, jump data displayed improved unilateral jump distance (both dominant and non-dominant legs) with increased maturation (see figure 2). Literature pertaining to this topic share analogous conclusions suggesting there are both physical and neural adaptations that occur with physical maturation and therefore improve subsequent jump performance, as observed in sprinting (Asadi et al., 2018; Murtagh et al., 2017). Murtagh et al., (2017), specifies adaptations such as increases in muscle size, motor unit activation, and therefore the potential muscular output may all contribute to the improvements observed in jump performances. This statement is supported by Meyers (2016), who displayed increases in absolute vertical and horizontal forces as maturation increased when sprinting, likely due to the neural and muscular advancements associated with maturation. The improvements in mean sprint times and jump distance that occurred congruently with increased maturation were not significant. It is hypothesised that this lack of significance is due to the increased variation and spread within the circa data set.

The concepts of neuromuscular disconnect and adolescent awkwardness discussed by Hägglund & Waldén (2016), and Van Der Sluis et al., (2014), did not have a notable detrimental effect on sprint or jump performance, as supported by the findings of Lloyd et al., (2016a) and Meyers (2016). Despite these comparable outcomes, both the sprint and jump data revealed a larger individual spread of performances within the circa maturation group in comparison to the pre and post groups (see figures 1 and 2); suggesting performance within this circa group is more variable. It is hypothesised this variability is due to the highly genetic and variable nature of individual growth which is maximised during this maturation period due to the onset of PHV. The concept of adolescent awkwardness is currently under-researched and there is little definitive evidence to suggest any true implications (Ford et al., 2011; Meyers et al., 2017). The phenomenon is characterised by a rapid increase in physical growth, specifically within the bones of the trunk and limbs, causing a temporary disconnect between the associated musculature and nervous system, resulting in a disruption in motor coordination (Philippaerts et al., 2006). It could be assumed, that those who exhibit more rapid, and/or greater physical growth, may in fact be more susceptible to this perceived disconnect, which would help explain the larger variability within the circa data. Further investigation into this concept is warranted to provide insight into the possible implications of this phenomenon on both performance and injury. It is important to note that the participants who exhibited the greatest variability from the circa group mean, were not those individuals' within the PHV calculations ±0.592 y error, as indicated by Meyers et al., (2017).

Current literature states that during the adolescent growth phase (circa period), incidence of traumatic injuries (a single identifiable event) increases, with mechanisms such as joint stiffness, decreased bone density and abnormal movement mechanics likely contributing to the change (Ford, Myer, & Hewett, 2014; Van Der Sluis et al., 2014; Van Der Sluis, Elferink-Gemser, Brink, & Visscher, 2015). Overuse injuries (repeated micro trauma with no identifiable single event) were seen to increase post PHV, with Van Der Sluis et al., (2015), suggesting that the increased susceptibility to injury is due to changes in muscular properties and tendon strength occurring after the maturational growth of bones and increase in muscular strength. The TJ test used within this study did not provide a rate of injury occurrence, but it could be reasonably assumed that those who are more prone to injury would display higher injury markers than other populations (Fort-Vanmeerhaeghe et al., 2017). The TJ scores revealed no significant differences between total scores, or any specific injury marker between maturation groups. It is believed that these findings can be attributed to the large variability within abilities across all maturation groups. The singular modified test, although deemed reliable during this study (ICC = 0.971), which is accordance with the findings of similar studies (Fort-Vanmeerhaeghe et al., 2017; Herrington, Myer, & Munro, 2013), may lack applicability due to the complex, individualised, and variable nature of the injury markers (Read, Oliver, de Ste Croix, Myer, & Lloyd, 2017). It is recommended that a more robust testing battery be implemented when trying to quantify the markers of injury, or injury incidence within a non-athletic male youth population.

Conclusion

The results of this study suggest that biological maturation has a significant influence on anthropometric variables and sprint performance, whilst also positively influencing horizontal jump performance. These findings are consistent with literature surrounding these concepts (Asadi et al., 2018; Meyers, 2016; Meyers et al., 2017; Murtagh et al., 2017) and are likely due to the influence of the musculoskeletal growth that occurs during the adolescence (Meyers, 2016; Murtagh et al., 2017). Data suggests that individuals' within their adolescent growth spurt (circa group) exhibit a larger variability in sprint and jump performance when compared to those in the pre or post PHV stages. It is hypothesised this is due to genetic factors that dictate the rate and intensity of musculoskeletal growth. Those who exhibit a steeper growth curve may be more prone to exhibiting a phenomenon known as adolescent awkwardness (Van Der Sluis et al., 2014). It is recommended that further research surrounding this neuromuscular disconnect is performed to identify its impact on the adolescent population, and the possible implications this disconnect may have on specific injury markers. It would also be beneficial to identify the effects of neuromuscular training interventions and their effectiveness of decreasing the prevalence of injury markers within youth. Results of this study display the key anthropometric and performance differences between children of similar ages. Further research into the kinematic variables such as step length, step frequency and contact times within the non-athletic youth setting would help to identify the underlying mechanisms behind these observed differences. It is also recommended that future research into school-based male youth include a measure of habitual physical activity to allow conclusions to be made about the over-arching activity levels of the cohort. Finally, investigations into the timing (pre, circa post PHV) of specific training interventions to improve sprint and jump performance is also warranted due to the differences observed within this study, and the implications these may have for motor skill acquisition and motor refinement.

CHAPTER 3: THE EFFECTIVENESS OF PROGRESSIVE AND TRADITIONAL COACHING STRATEGIES TO IMPROVE SPRINT AND JUMP PERFORMANCE ACROSS VARYING LEVELS OF MATURATION WITHIN A GENERAL YOUTH POPULATION.

Abstract

Literature pertaining to youth development and biological maturation has identified the importance of understanding the physical, intellectual and emotional needs of an adolescent athlete. By doing this effectively, it is likely a coach/trainer can maximise motor and sporting performances. Previous literature has investigated the physical differences that occur across levels of biological maturation, and how these influence the effectiveness of training programmes. One factor that has not been investigated in-depth are the coaching methods that best enhance skill acquisition and motor performance within each maturation level, despite the previously identified differences in neural and cognitive physiology. The purpose of this study was to compare the use of a 'traditional' and 'progressive' coaching style over a period of five weeks, to train a general male youth population with the aim of improving sprint and jump performances, whilst also assessing enjoyment to comment on long term application. Anthropometrics, maximal sprint times, unilateral jump distances and repetitive tuck jump scores were measured to characterise performance within this population. Sprint kinematics were also analysed via high speed footage to provide information to the underlying mechanisms behind any changes that occurred throughout the intervention. Results of this study revealed significant (p>0.05) pre/post differences in various sprint, jump and anthropometric measures across maturation groups. Despite being non-significant, training group differences (p>0.05) suggested each of the maturational levels displayed a tendency to favour a particular coaching or control condition. Pre-PHV groups responded most effectively to the progressive style of coaching, displaying up to 11% improvement in horizontal jump performances, and -0.7 to -2.7% improvements in 5m, 10m and 20m sprint times, despite also showing the largest increase in injury markers via a 25.8% increase in tuck jump scores. The circa-PHV group produced their greatest improvements in the traditional style intervention, as displayed through significant improvements (p<0.05) in 20m sprint times and dominant-leg horizontal jump performance, however also revealing the greatest deterioration in pre/post tuck jump scores (14.2%). Finally, the post-PHV group displayed

the greatest sprint and jump improvements in the control setting, suggesting the natural benefits gained through adolescent development alone were greater than the influence of the training interventions for this maturation group. Sprint kinematics supported the changes in sprint times with step frequency and step length showing similar trends to those observed in previous literature. In conclusion, it is suggested that matching coaching strategies and delivery techniques to the period of biological maturation may have implications for both performance and athlete safety. It is also determined that increases in athlete power output either through increased neural maturation, or adaptation to a training stimulus, may provide an increase in injury markers if the tuck jump is used as a tool to characterise risk in these areas. It is recommended a variety of coaching approaches is utilised within a male youth setting until future research can further substantiate the underlying mechanisms responsible for these changes observed within this study.

Introduction

The use of long-term athlete development (LTAD) models have become widely discussed and implemented by coaches within sporting programmes working within the youth setting (Ford et al., 2011; Lloyd et al., 2009; Lloyd et al., 2015; Lloyd et al., 2015). These models aim to cater to the highly variable and non-linear nature of adolescent development by targeting age appropriate activity in an athlete-centred manner (Lloyd et al., 2015; Oward et al., 2009). Youth coaches invested in these models promote discrete alterations in training focus throughout their sporting journey to allow individual growth and help create a positive relationship with exercise, ultimately aiming to preserve long-term participation (Lloyd et al., 2015; Oward et al., 2009). The need for variety and individualisation within training regimes is critical due to the variable onset of peak height velocity (PHV) during the adolescent growth spurt. This gene-based, hormone-driven biological process dictates the rate and timing of physical and neurological maturation (Mao et al., 2013; Sovio et al., 2009). Due to the unpredictability in the length and intensity of this growth phase, it is common to see a large range in physical, psychological and emotional aptitudes within individuals of a similar chronological age (Mirwald et al., 2002). Accompanying these changes are a rise in the risk of both structural and soft tissue injuries due to the increased rate of growth in bones and muscles (Hägglund & Waldén, 2016; Van Der Sluis et al., 2014). Neurologically, this process includes the progressive myelination of axons, accompanied by synaptic and axonal pruning (De Bellis, 2001). This development may be expressed through alterations in regular behaviour, risk-taking, emotional responsiveness, as well as the individuals need for cognitive stimulation and sensation (Ladouceur, Peper, Crone, & Dahl, 2012), and also through a phenomenon identified as 'adolescent awkwardness' which is used to describe the process of long bone growth prior to muscular growth, which can lead to a period of disruption in motor coordination (Lloyd et al., 2009). The corresponding effects of these neurological and behavioural adaptations may have implications for learning needs, learning effectiveness and learning styles (Alexander, Schallert, & Reynolds, 2009).

Past research has investigated strategies such as Athlete-centred learning (Kidman, 2005), Game sense (den Duyn, 1997), Teaching games for understanding (TgfU) (Bunker & Thorpe, 1982), and numerous types of coach-feedback strategies (Ille, Selin, Do, &

Thon, 2013; Rucci & Tomporowski, 2010), aimed at optimising learning within a range of populations. Experimental studies investigating these topics have highlighted improvements in recognition performance, motor skills, emotional aptitude and decision making (Duran, 2016; Porter, Wu, & Partridge, 2010; Zeng, Liu, Zhang, Tao, & Dong, 2016), which prompt further examination into their application in various contexts. Despite these investigations, there is limited research into the success of these strategies during arguably one of the most important developmental ages for youth; PHV. These pre-mentioned coaching strategies share key overlapping themes with slight variations in application, delivery and/or targeted outcomes. Key similarities between these strategies include the importance placed on the athletes need to interact, apply and discover learning for themselves, have fun, group interaction, problem solving, decision making and finally, learning through numerous interactions with technical, tactical or physical material in a range of contexts; which will collectively be referred to as 'progressive' coaching from here-on and so-forth. These methods are in contrast to a more traditional approach to coaching which typically encompass technical drill-based methods, providing repetition and technical awareness for the individual prior to competing in the sport (Light, 2004). A study by Blomqvist, Luhtanen, and Laakso (2001), utilised a traditional style of coaching alongside a 'strategy-orientated' approach and identified that badminton serving skills improved most when taught utilising the traditional methods. This approach provides an intimate context to teach, refine, and modify sport specific movements through repetition and exposure to the required technical skills (Gabbett et al., 2006; Light, 2004; Turner & Martinek, 1999), and may provide a more effective coaching style in some environments.

Based on current literature surrounding the individual variation in physical, cognitive and emotional aptitudes within the adolescent population, a coaches' role is to ensure learning is maximised through purposeful pursuits to stimulate the minds of youth via planned and strategic coaching methods. Previous successful application of TGfU, Game sense, Athlete-centred coaching and also a traditional approach to coaching, suggest their use throughout a range of movement contexts is warranted; however, they may be difficult to implement within some individual sports, or training groups, due to the lack of team and group interactions available, and the level of buy-in from coaches (Light, 2004). If learning and retention can be maximised within these cohorts of varying levels of biological maturation, then athlete independence, enjoyment, knowledge and physical longevity within sport can be improved; ultimately keeping them interested in the sport for longer.

The aim of this study is to build on the findings of Radnor, Lloyd, and Oliver (2017) and further inform literature pertaining to within-PHV characteristics. This study will utilise two different coaching approaches (traditional and progressive) to identify the most effective strategy to improve sprint and jump performance within pre, circa and post-PHV maturation groups. Injury markers, movement kinematics and performance measures will provide insight into alterations in movement that occur during the intervention, whilst enjoyment will be measured to provide insight into athlete engagement. Due to the success of the TGfU and Game sense approaches in different cohorts, it is hypothesised that a progressive coaching style will produce the greatest improvements in sprint and jump performance within the pre and post maturation groups when compared to the traditional coaching group, as well as display a decrease in injury markers. It is hypothesised that the circa maturation group will respond best to the traditional coaching methods, as the individual focus and direct feedback may limit the detrimental influence of adolescent awkwardness. Finally, it is hypothesised that enjoyment will remain consistent throughout both coaching strategies because of the short-term application of the intervention.

Methods

Study design

This study utilised a semi-randomized test - retest design, which compared descriptive data from three distinct maturation groups (pre, circa, and post-PHV), under three separate conditions (traditional coaching, progressive coaching, and control), within the targeted male youth population of a single high school. Those individuals within the control and training groups were pre-determined due to schooling physical education class allocation, however the traditional and progressive groups were randomised based on individual maturation representation. Representative groups were allocated post pre-testing with the use of a sex-specific PHV calculation (Mirwald et al., 2002) which utilises height, seated height and limb length, to measure maturation offset (pre < -0.50, circa -0.49 to +0.49, post> +0.5) (Meyers, Oliver, Hughes, Lloyd, & Cronin, 2017). Despite this equation having a reported variance of ± 0.592yrs (Meyers et al., 2017), the allocations were made in accordance with similar studies (Meyers et al., 2017; Meyers, 2016), and to allow better distribution across maturation groups within this population.

Participants

A total of 111 youth males (age 13.2 - 15.7yrs; maturity offset -1.0 to 2.6yrs) from a single high school volunteered for this project. A completed health questionnaire with no contraindications, and guardian consent were required to partake in this study. There were no fitness, or sporting requirements of the participants as a representation of general youth ability was sought. Due to the use of a single high school there was a mix of athletic and non-athletic individuals within the tested population. Inclusion criteria for data analysis required pre and post testing completion, in addition to an 80% completion of training sessions for the training groups. These criteria led to a 25.2% dropout from the initial 111 volunteers (traditional = 9.9%, progressive = 7.2%, control 8.1%). Full data sets were recorded for a total of 83 participants (traditional n = 28, progressive n = 30, control n = 25), with Table 1 displaying these group characteristics per training and maturation group. Ethical approval was granted for all procedures from the institutes' ethics committee.

Table 1: Descriptive anthropometric statistics for training and maturation groups (Mean ± SD)

Maturation group	Training Group	N	Age (y)	Height (cm)	Weight (kg)	Maturity offset (y)
Pre-PHV	CT	3	13.5 ± 0.2	155.7 ± 1.5	43.1 ± 2.1	-0.8 ± 0.2
	Trad	4	13.9 ± 0.7	154.7 ± 2.9	45.4 ± 3.1	-0.7 ± 0.1
	Prog	4	13.5 ± 0.7	156.8 ± 5.3	49.4 ± 4.5	-0.7 ± 0.1
Circa-PHV	CT	14	14.1 ± 0.7	163.4 ± 5.3	52.2 ± 8.0	0.0 ± 0.3
	Trad	7	14.1 ± 0.5	162.7 ± 6.3	53.4 ± 10.3	0.1 ± 0.3
	Prog	10	14.2 ± 0.5	165.1 ± 4.4	54.4 ± 7.7	0.0 ± 0.2
Post-PHV	CT	8	14.7 ± 0.7	173.3 ± 7.2	59.2 ± 6.7	1.3 ± 0.4
	Trad	17	14.7 ± 0.5	173.3 ± 6.1	62.9 ± 10.2	1.2 ± 0.6
	Prog	16	14.8 ± 0.4	172.7 ± 5.7	66.0 ± 8.2	1.2 ± 0.5

Note: CT = Control group; Trad = Traditional group; Prog = Progressive group

Experimental procedures

Both the training and control groups were required to attend a pre and post-testing session, which lasted approximately 50mins each and were separated by a six-week period. Additionally, training groups participated in five training sessions lasting between 40 and 50mins each, dependent on school timetabled class durations. All sessions were performed in bare feet on a wooden gymnasium floor in self-selected active wear. A standardized warm up was led prior to each session, which lasted approximately 12mins and consisted of dynamic, progressive exercises targeting the whole body initially, then the lower limb specifically. Familiarization occurred prior to the commencement of each pre and post-test via verbal instruction and a visual demonstration. Each participant was provided the opportunity to practice each movement prior to the recorded trials. The five training sessions utilised with both the traditional and progressive training groups aimed to improve sprint technique via several mechanical factors including body positioning, lower limb mechanics, upper limb mechanics, and ground contact characteristics (Cissik, 2005b; Dick, 1989; McFarlane, 1993; Seagrave, Mouchbahani, & Donnell, 2009) as per Appendix 2. The traditional and progressive coaching strategies were characterised by several key strategical differences (Table 2), with technical aspects derived from Benz, Winkelman, Porter and Nimphius (2016); Cissik, (2005a), (2005b).

Table 2: Strategical differences of the traditional and progressive coaching styles

Traditional	Progressive
- Coach led	- Coach and athlete led
- Provided information to athlete	- Guided athletes to discover learning
- Individual feedback given to athletes	- Feedback provided through individual questioning and group discussion
- Activities and drills performed individually	- Group and pair activities used
- Focus on individual skill improvement	- Focus on group culture and interaction
- Repetition and technical focus	- Problem solving required
- No group-based competition	- Competition within group

Each session, the two coaches would change the group they delivered to as to ensure there was no bias towards personal delivery characteristics that may influence the PACES survey and enjoyment outcomes. Both coaches were experienced (8+ years) in coaching youth sport and were current coaches in the industry. Each coach consciously focussed on a fun and engaging delivery style which included variable tone and pitch in voice, open body-language, and a high level of energy, irrespective of whether they were with the traditional or progressive group as to ensure differences were only evident in the pre-determined coaching strategies (Table 2).

Data collection

Anthropometrics

Height, seated height and weight were measured during pre-testing to provide information for the PHV calculation (Mirwald et al., 2002). Standing height was measured via a free-standing stadiometer, with the participants feet shoulder width apart and the chin and line of sight parallel to the floor. The headpiece was lowered firmly on the centre of the participants head whilst they were standing with erect posture. Seated height was measured whilst sitting on a 30cm anthropometric box placed against a wall with a tape measure aligned vertically from centre of the box. Participants had their legs together and hands rested on their knees. The lower back was firmly against the wall at the rear of the box and the chin and eye line were parallel to the floor. The headpiece was lowered firmly on to the participants head, ensuring a right angle was kept with the wall. Both standing and seated heights were measured to the nearest mm. Weight was taken on a set of electronic scales which were zeroed prior to each participants measurement.

Sprint performance

Participants performed three maximal effort 20m sprints (2mins rest between each trial), utilising a standing split stance with their preferred foot placed on the starting line 0.5m back from first timing light (White & Gunter, 2002). A dual-beam-modulated SWIFT timing light system (Wacol, Australia), captured performance times using four sets of lights placed at the zero, 5m, 10m and 20m marks, at a height of 0.85m (to top of tripod), with the lane width approximately 3m. The initial timing light gate (0m) was set lower (65cm to the top of tripod) than the other gates to account for the likely hunched start positions of the participants. Each trial began with a forward movement of the torso, as opposed to a rocking motion where momentum could be generated prior to first foot movement. Once instructed to step up to the line, the participant was free to commence the trial in their own time to remove any variability in reaction times. Similar protocols have been deemed to have a high level of reliability by previous literature, with coefficient of variation values ranging from 1.9-2.6% and intra-class correlation coefficients of 0.89 – 0.95 (Moir et al., 2004).

Sprint kinematics

Two high-speed cameras (Casio Exilim, ex-zr200) capturing at 240fps on fixed tripods (set at 0.8m to base of tripod) were placed to capture a sagittal view perpendicular to the line of sprint. Camera one was set at a 2.5m distance from the start line and 6m perpendicular to the centre of the runway, which allowed the capturing of the first 5m of each sprint. Camera two was set at the 15m mark, 9m perpendicular to the runway with a field of view at approximately 12.5m – 17.5m of the line of the sprint. Calibration markers (1.5m in length) were placed central to both cameras to replicate similar distances to those observed in comparable populations within relevant literature (Lockie, Murphy, & Spinks, 2003; Standing & Maulder, 2017) and to minimize parallax error. Data analysis of the sprint kinematics required the use of Silicon-coach pro 7 (Dunedin, New Zealand) to measure the following variables, with metrics derived from the recommendations of Standing and Maulder, (2017):

Step length (m) - Horizontal distance between the point of touchdown of one foot (furthest point) and the touchdown of the following foot.

Step rate (Hz) – The amount of steps per second, calculated via the following equation, 1/(stance + flight time).

Stance time (s) - Duration of the time taken from the last frame before contact with the ground, to the last frame with contact.

Flight time (s) - Duration of the time taken from the last frame displaying contact with the ground, to the frame prior to ground contact.

Unilateral horizontal jumps

Maximal unilateral horizontal jump performance was obtained via three jumps for distance from each leg (take-off one leg and land with two), with approximately 2mins rest between trials (alternating legs each trial). Measurements were taken from the rear-most heel on a successful landing. An unsuccessful landing consisted of an individual falling backwards, stepping backwards, or putting their hands down behind the rear-most heel (these trials were repeated). Hands were free to move throughout the movement and no coaching or technical cues were given. Similar protocols for this test have identified that the horizontal jump is a reliable test with ICC values greater than 0.85.

Tuck jump assessment

A single 10s bilateral tuck jump (TJ) assessment was performed and qualitatively marked against a modified rubric (see Chapter 2, Table 1) (Fort-Vanmeerhaeghe et al., 2017). Intra-rater reliability statistics (ICC) for the modified TJ assessment was calculated at 0.971 (substantial) and a 93% PEA, with Kappa scores ranging from 0.615 to 1.00 ($p<0.05$) for each of the 10 individual variables within the rubric. On the gym surface where the test was to be performed, tape was used to create a box with edges 41cm in length and 35cm wide, which the participants were instructed to remain on if possible (Fort-Vanmeerhaeghe et al., 2017). This assessment required the participant to perform continuous tuck jumps for a period of 10s within the specified area (if possible). Instructional cues consisted of the following; “bring knees to chest”, “continuous jumps for 10s”, “jump as high as you feel comfortable”. Two high-speed cameras (Casio Exilim, ex-zr200) capturing at 120fps on fixed tripods (set at 0.8m to base of tripod) provided frontal and sagittal views of the participant during their tuck jump assessment. Scores were allocated via post-session video analysis and compared against a severity based kinematic marking criteria (see Chapter 2, Table 1).

Paces survey

Enjoyment levels for both training groups was sought through a PACES questionnaire (Motl et al., 2001) which was administered at the completion of the final session. Instructions were to fill out the survey as honestly as possible, and to take the time to read and think about each question carefully.

Statistical analysis

A post-only spreadsheet from Hopkins (2006a), was utilised to analyse pre/post changes within maturation levels across training groups for all performance measures and kinematic variables. Differences between log-transformed measures are expressed as percentage differences, with effect sizes, 90% confidence limits, *p* values and qualitative inferences used to supplement these changes. A difference was deemed *unclear* if confidence limits of the effect statistic overlapped zero. If a result was deemed as *clear*, effect sizes were awarded per the descriptors of Hopkins (2002); 0 – 0.2 *trivial;* 0.2 – 0.6 *small;* 0.6 – 1.2 *moderate*; 1.2 – 2.0 *large*; 2.0 – 4.0 *very large*. Statistical significance was awarded for variables with a *clear* effect size and $p<0.05$.

The mean of the two best sprint and horizontal jump trials was utilised for each participant and used as comparative scores as per the recommendations of Maulder, Bradshaw, & Keogh (2008). Further statistical analyses compared change scores for the 5m, 10m, and 20m sprints, as well as the HJD, HJND, TJ score, and kinematic variables across maturation levels between control, traditional and progressive training groups. A spreadsheet for the analysis of pre-post parallel groups' trials (Hopkins, 2006b), was utilised to derive net percentage changes, *p* values, 90% confidence limits, and effect sizes; whilst qualitative descriptors were used to describe effect sizes (Batterham & Hopkins, 2006).

The PACES enjoyment survey was analysed via a spreadsheet comparing group means (Hopkins, 2007). This provided mean and standard deviations for both training groups accompanied by *p* values and effect sizes to interpret the magnitude of difference (Hopkins, 2002).

Results

Anthropometrics and performance measures

Pre and post-test mean and SD for sprint and jump metrics can be found in Tables 3 and 4. Log-transformed within-group differences and between-group differences can be observed in Tables 5 and 6, and 7 and 8, respectively.

Pre-testing data identified that there were no significant differences (p>0.05) between training-groups of the same maturation level prior to intervention. It was observed that height, weight and seated height increased significantly for all training groups (p<0.05) over the five-week intervention without maturational grouping. The exception to this was the control-group seated height which had a non-significant *trivial-small* increase (0.4% ± 90%CL = 0.9%; p = 0.479). Maturational grouping displayed that the pre PHV and circa-PHV groups significantly increased height, weight and seated height (p< 0.05) during the intervention period, with the post-PHV group showing significant differences in height (0.9% ± 0.7%, p = 0.035) and weight (2.2% ± 0.8%, p < 0.001) only.

When comparing pre/post change scores, it was revealed that *small-large* significant differences in TJ scores between the control and progressive-groups (p = 0.018) were evident. No significant differences were observed for any anthropometric, sprint or horizontal jump measures when maturation was utilised as a covariate and compared across training-groups (see Tables 7 and 8). Despite being non-significant, *clear* outcomes were identified for many performance-based metrics.

When comparing strictly pre-PHV means between training-groups, *clear* outcomes were identified for the progressive-group who displayed the largest change in mean 5m (-2.1% ± 2.9%, p = 0.080), 10m (-1.1% ± 2.7%, p = 0.395), and 20m (-2.7% ± 3.2%, p = 0.136) sprint times, with effect sizes ranging from *trivial* to *moderate* (see Table 5). Group sprint means (5m, 10m, and 20m) for both the traditional and control pre-PHV groups were up to 4.4% slower when compared to pre-assessment times (see Table 5). This trend continued within the jump data, with the progressive-group pre-PHV eliciting *trivial* to *large* improvements in HJD (10.8% ± 10.7, *p* = 0.098), HJND (11.0% ± 6.2%, *p* = 0.027) performances (see Table 4). Despite traditional and control-groups also eliciting positive jump performances (4.3% to 7.6%) effect sizes were *unclear – moderate* and statistically non-significant (*p*>0.05). Contrasting to these results, pre-PHV tuck jump scores showed the largest deterioration within the progressive-group (25.8% ± 22%, *p* = 0.073), with the traditional and control-groups improving their scores by 15.6% ± 84.9% (*p* = 0.547), and 11% ± 49.7% (*p* = 0.506), respectively (see Table 4 and 6).

When comparing circa-PHV groups, decreased sprint times were observed in each of the 5m, 10m, and 20m distances across all training-groups with mean improvements of -0.1% to -3.1% (see Tables 3 and 5). The circa-PHV progressive (-1.6% ± 1.2%, *p* = 0.043) and control (-2.2% ± 1.7%, *p* = 0.036) 20m sprint times were the only statistically significant improvements in sprint times, both with *trivial* to *small* effect sizes. Although non-significant, the traditional-group elicited the greatest improvements in circa-PHV HJD (10.1% ± 4.9%, *p* = 0.008), and HJND (9.9% ± 8.2%, *p* = 0.060) scores, but as seen in the pre-PHV groups, the training-group who witnessed the greatest gains in horizontal jump distance also displayed the greatest deterioration in TJ score (14.2% ± 29.1%, *p* = 0.350), in contrast to the control group who improved by 8.9% ± 13.4 (*p* = 0.213) (see Table 6).

When comparing post-PHV change scores, *unclear* results were identified for all training-groups for 5m sprint times, with pre/post change scores ranging from -0.9% to 0.7%. Post-PHV 10m sprint times displayed *trivial* to *moderate* improvements for the traditional (-2.1% ± 2.7, *p* = 0.177) and control (-0.9% ± 1.7%, *p* = 0.321) groups, with the progressive-group slowing by 0.6% ± 1.6% (*p* = 0.538). Significant improvements were identified in control (*p* = 0.028) and traditional (*p* = 0.030) 20m sprint times, with the progressive-group improving by a non-significant -0.3% ± 1.9% (*p* = 0.748). All HJD and HJND performances improved significantly ($p<0.05$) between 3.8% and 9.3% at the post-PHV level across training groups, with TJ scores increasing between 1.9% and 12.9% (see Tables 4 and 6).

When removing maturation as the covariate and observing training groups in their entirety, there were significant changes for several sprint and jump performance measures. *Trivial* to *small* improvements were seen in the control (-1.8% ± 1.1%, p = 0.008), and traditional (-1.8% ± 1.1%, p = 0.008) 20m sprint times, as well as *small* to *moderate* improvements in HJD and HJND performances for all training groups, irrespective of maturational grouping (p<0.05) (see Tables 4 and 6).

Kinematic measures

Whilst incorporating maturation and comparing training-group kinematic characteristics, there were several significant changes within the circa and post-groups, with no significant (p>0.05) differences between training-group kinematic variables at the pre-PHV level (see Appendix 3).

The circa-PHV progressive-group measures displayed significantly larger 15m flight times (14.3% ± 8.9%, p = 0.015), and significantly lower step frequencies at the second-step (9.5% ± 8.0%, p = 0.036) and 15m-step (9.8% ± 7.8, p = 0.028) when compared to the circa-PHV control-group (see Appendix 3). During step-two, the circa-PHV control group displayed an increase in step-length (7.7% ± 6.1%, p = 0.038) and shorter flight time during step-one (-34.3% ± 22.8%, p = 0.026) when compared to the traditional-group change scores. Significant (p<0.05*) small-large* effect sizes were identified between the circa-PHV traditional and progressive contact times at step-two (9.3% ± 6.9%) and 15m (7.7% ± 5.3%), as well as step-frequency during step-two (8.8% ± 6.5%) (see Appendix 3).

Comparing between groups at the post-PHV level, control-groups displayed *trivial-moderate* longer step length during step-two (p = 0.039) and three (p= 0.041) when compared to both progressive and traditional-groups, respectively (see Appendix 3). The post-PHV control-group also displayed a shorter contact time during step-one (-6.9% ± 5.5%, p = 0.031) when compared to progressive-group, and a lower step frequency during step-one (13.7% ± 8.1%, p = 0.010) when compared to traditional group. The post-PHV traditional-group displayed a *trivial* to *moderate* difference in step-one step-length, in comparison to the progressive-group (p = 0.045).

When maturation was removed as a covariate and training-groups were analysed in their entirety, significant differences in step frequency were observed between control and traditional-groups during step-one (p = 0.032). It was also determined that the traditional-group had a significantly faster contact time at the 15m mark (-5.4% ± 3.7%, *p* = 0.018) than the progressive-group.

Despite being non-significantly different to improvements witnessed in other training-groups, pre/post comparisons revealed the control-group had a significant increase in step 2 step-length (4.7% ± 2.1%, *p* = 0.001), accompanied by a *trivial* to *moderate* increase in contact time during step-one (0.217s – 0.224s, *p* = 0.025). Significant decreases were observed in traditional-group contact time (*p* = 0.001, ES = *small-moderate*) and flight time (*p* = 0.019, ES = *trivial-small*) at the 15m recording, with mean changes ranging from -5.8% to -7% for both of the observed metrics. The progressive group significantly increased mean 15m flight time (0.091s – 0.098s, *p* = 0.029, ES = *trivial-moderate*) and 15m step length (1.70m – 1.75m, *p* = 0.023, ES = *trivial-small*), over the course of the intervention.

The PACES enjoyment survey revealed no significant differences within maturation and coaching groups (*p*>0.05), with mean scores ranging from 49.7 to 61.4. The circa-PHV group displayed the only *clear* difference between traditional and progressive coaching methods, with the progressive being identified as more enjoyable with a *trivial-large* effect size (*p* = 0.090).

Table 3: Pre and post sprint mean ± SD for training and maturation groups

Metric	Maturation group	Test	Control Mean	±	SD	Traditional Mean	±	SD	Progressive Mean	±	SD
5m (s)	All	Pre	1.16	±	0.08	1.15	±	0.07	1.16	±	0.08
		Post	1.16	±	0.08	1.15	±	0.07	1.16	±	0.07

	Pre-PHV	Pre	1.15 ± 0.04			1.17 ± 0.05			1.21 ± 0.07	
		Post	1.18 ± 0.05			1.22 ± 0.06			1.18 ± 0.08	
	Circa-PHV	Pre	1.18 ± 0.09			1.19 ± 0.10			1.18 ± 0.05	
		Post	1.18 ± 0.09			1.18 ± 0.06			1.18 ± 0.05	
	Post-PHV	Pre	1.13 ± 0.04			1.12 ± 0.05			1.14 ± 0.10	
		Post	1.12 ± 0.07			1.12 ± 0.06			1.15 ± 0.09	
10m (s)	All	Pre	2.01 ± 0.13			1.98 ± 0.14			2.00 ± 0.15	
		Post	1.99 ± 0.17			1.95 ± 0.15			1.98 ± 0.14	
	Pre-PHV	Pre	1.98 ± 0.04			2.07 ± 0.09			2.07 ± 0.14	
		Post	2.02 ± 0.06			2.11 ± 0.09			2.05 ± 0.12	
	Circa-PHV	Pre	2.05 ± 0.16			2.04 ± 0.20			2.03 ± 0.09	
		Post	2.02 ± 0.14			2.00 ± 0.11			1.98 ± 0.19	
	Post-PHV	Pre	1.95 ± 0.07			1.93 ± 0.10			1.96 ± 0.18	
		Post	1.93 ± 0.10			1.89 ± 0.14			1.97 ± 0.17	
20m (s)	All	Pre	3.52 ± 0.26			3.46 ± 0.28			3.49 ± 0.30	
		Post	3.45 ± 0.23*			3.40 ± 0.23*			3.46 ± 0.27	
	Pre-PHV	Pre	3.47 ± 0.04			3.70 ± 0.22			3.66 ± 0.29	
		Post	3.50 ± 0.09			3.70 ± 0.15			3.56 ± 0.20	
	Circa-PHV	Pre	3.60 ± 0.30			3.57 ± 0.37			3.55 ± 0.19	
		Post	3.52 ± 0.26*			3.45 ± 0.22			3.49 ± 0.16*	
	Post-PHV	Pre	3.40 ± 0.15			3.37 ± 0.20			3.42 ± 0.35	
		Post	3.33 ± 0.18*			3.31 ± 0.19*			3.41 ± 0.34	

Note: * = significantly different to pre-test (p<0.05).

Table 4: Pre and post jump mean ± SD for training and maturation groups

Metric	Maturation group	Test	Control Mean ± SD	Traditional Mean ± SD	Progressive Mean ± SD

HJD (m)	All	Pre	1.55	±	0.21	1.65	±	0.18	1.59	±	0.25
		Post	1.65	±	0.22*	1.74	±	0.18*	1.70	±	0.23*
	Pre-PHV	Pre	1.55	±	0.12	1.50	±	0.15	1.46	±	0.17
		Post	1.63	±	0.16	1.61	±	0.08	1.61	±	0.08
	Circa-PHV	Pre	1.54	±	0.24	1.57	±	0.20	1.60	±	0.23
		Post	1.62	±	0.26	1.72	±	0.20*	1.68	±	0.14
	Post-PHV	Pre	1.59	±	0.19	1.71	±	0.14	1.63	±	0.28
		Post	1.73	±	0.14*	1.78	±	0.17*	1.73	±	0.30
HJND (m)	All	Pre	1.48	±	0.21	1.58	±	0.17	1.52	±	0.25
		Post	1.56	±	0.22*	1.66	±	0.18*	1.63	±	0.24*
	Pre-PHV	Pre	1.45	±	0.14	1.48	±	0.15	1.41	±	0.12
		Post	1.51	±	0.11	1.54	±	0.09	1.56	±	0.08*
	Circa-PHV	Pre	1.46	±	0.24	1.48	±	0.19	1.50	±	0.22
		Post	1.52	±	0.26	1.62	±	0.20	1.60	±	0.16
	Post-PHV	Pre	1.53	±	0.20	1.64	±	0.14	1.56	±	0.29
		Post	1.65	±	0.14*	1.71	±	0.18*	1.66	±	0.31
TJ Score	All	Pre	13.9	±	2.6	11.6	±	3.0	12.0	±	2.9
		Post	13.1	±	2.8	12.4	±	3.0	13.5	±	2.7*
	Pre-PHV	Pre	15.0	±	3.0	13.0	±	0.8	11.8	±	1.5
		Post	12.7	±	2.5	12.0	±	3.4	14.8	±	1.5
	Circa-PHV	Pre	13.8	±	2.1	12.4	±	3.0	11.5	±	3.2
		Post	12.6	±	2.4	14.1	±	3.1	12.7	±	3.6
	Post-PHV	Pre	13.8	±	3.5	11.0	±	3.2	12.1	±	2.9
		Post	14.1	±	3.6	11.8	±	2.8	13.5	±	2.1

Note: * = significantly different to pre-test ($p<0.05$).

Table 5: Percentage change (90%CL) in sprint metrics within maturational groups across control, traditional and progressive training groups

Metric	Maturation	Control						Traditional						Progressive					
		%diff,	±	CL	(ES,	±	CL)	%diff,	±	CL	(ES,	±	CL)	%diff,	±	CL	(ES,	±	CL)
5m (s)	All	0.0,	±	1.5	(-0.01,	±	0.22)	0.1,	±	1.4	(0.02,	±	0.21)	0.1,	±	1.1	(0.01	±	0.16)
	Pre-PHV	3.3,	±	10.4	(0.57,	±	1.72)	4.4,	±	5.2	(0.70,	±	0.83)	-2.1,	±	2.9	(-0.27	±	0.37)
	Circa-PHV	-0.3,	±	2.0	(-0.03,	±	0.25)	-1.1,	±	3.3	(-0.11,	±	0.35)	-0.1,	±	1.9	(-0.03	±	0.39)
	Post-PHV	-0.9,	±	2.4	(-0.24,	±	0.62)	-0.4,	±	1.6	(-0.07,	±	0.30)	0.7,	±	1.7	(0.09	±	0.20)
10m (s)	All	-0.7,	±	1.1	(-0.10,	±	0.17)	-1.4,	±	1.8	(-0.20,	±	0.26)	-0.7,	±	1.6	(-0.10	±	0.21)
	Pre-PHV	2.0,	±	6.6	(0.60,	±	1.91)	2.0,	±	3.2	(0.32,	±	0.51)	-1.1,	±	2.7	(-0.12	±	0.30)
	Circa-PHV	-1.1,	±	1.6	(-0.13,	±	0.20)	-1.5,	±	3.3	(-0.14,	±	0.30)	-2.6,	±	4.4	(-0.55	±	0.89)
	Post-PHV	-0.9,	±	1.7	(-0.24,	±	0.42)	-2.1,	±	2.7	(-0.41,	±	0.51)	0.6,	±	1.6	(0.06	±	0.18)
20m (s)	All	-1.8,	±	1.1	(-0.25,	±	0.15)*	-1.8,	±	1.1	(-0.23,	±	0.13)*	-1.1,	±	1.1	(-0.12	±	0.13)
	Pre-PHV	0.8,	±	5.0	(0.40,	±	2.33)	0.0,	±	3.4	(0.00,	±	0.41)	-2.7,	±	3.2	(-0.25	±	0.29)
	Circa-PHV	-2.2,	±	1.7	(-0.26,	±	0.19)*	-3.1,	±	3.3	(-0.27,	±	0.28)	-1.6,	±	1.2	(-0.27	±	1.21)*
	Post-PHV	-2.1,	±	1.5	(-0.43,	±	0.30)*	-1.7,	±	1.2	(-0.28,	±	0.20)*	-0.3,	±	1.9	(-0.03	±	0.19)

Note: %diff = percentage difference in means; CL = 90% confidence limits; ES = effect size; * = significant difference in pre/post means (p<0.05).

Table 6: Percentage change (90%CL) in jump metrics within maturational groups across control, traditional and progressive training groups

Metric	Maturation	Control		Traditional		Progressive	
		%diff, ± CL	(ES, ± CL)	%diff, ± CL	(ES, ± CL)	%diff, ± CL	(ES, ± CL)
HJD	All	6.4, ± 3.0	(0.43, ± 0.20)*	6.0, ± 2.1	(0.52, ± 0.19)*	6.7, ± 2.0	(0.41, ± 0.13)*
	Pre-PHV	4.8, ± 5.9	(0.34, ± 0.42)	7.6, ± 7.5	(0.50, ± 0.50)	10.8, ± 10.7	(0.63, ± 0.62)
	Circa-PHV	5.1, ± 4.5	(0.29, ± 0.26)	10.1, ± 4.9	(0.64, ± 0.32)*	5.4, ± 4.6	(0.36, ± 0.30)
	Post-PHV	9.3, ± 5.8	(0.63, ± 0.40)*	4.0, ± 2.7	(0.45, ± 0.30)*	6.5, ± 2.2	(0.35, ± 0.12)*
HJND	All	5.6, ± 2.9	(0.35, ± 0.18)*	5.4, ± 2.6	(0.45, ± 0.22)*	7.2, ± 2.1	(0.41, ± 0.12)*
	Pre-PHV	4.3, ± 11.3	(0.25, ± 0.63)	4.3, ± 7.9	(0.29, ± 0.53)	11.0, ± 6.2	(0.85, ± 0.49)*
	Circa-PHV	4.2, ± 3.8	(0.22, ± 0.20)	9.9, ± 8.2	(0.60, ± 0.50)	7.3, ± 5.9	(0.45, ± 0.37)
	Post-PHV	8.5, ± 6.5	(0.55, ± 0.43)*	3.8, ± 2.9	(0.42, ± 0.32)*	6.2, ± 2.1	(0.30, ± 0.10)*
TJ Score	All	-6.4, ± 12.3	(-0.35, ± 0.61)	6.8, ± 9.9	(0.23, ± 0.33)	13.1, ± 8.0	(0.47, ± 0.29)*
	Pre-PHV	-15.6, ± 84.9	(-0.48, ± 1.73)	-11.0, ± 49.7	(-1.34, ± 4.66)	25.8, ± 22.0	(1.29, ± 1.11)
	Circa-PHV	-8.9, ± 13.4	(-0.60, ± 0.81)	14.2, ± 29.1	(0.46, ± 0.89)	10.2, ± 20.8	(0.30, ± 0.59)
	Post-PHV	1.9, ± 36.1	(0.07, ± 1.09)	8.4, ± 11.7	(0.25, ± 0.35)	12.9, ± 10.4	(0.45, ± 0.37)*

Note: %diff = percentage difference in means; CL = 90% confidence limits; ES = effect size; * = significant difference in pre/post means ($p<0.05$); HJD = Horizontal jump dominant leg; HJND = Horizontal jump non-dominant leg.

Table 7: Percentage difference (90%CL) in sprint change scores within maturation groups and between training groups

Metric	Maturation	Control vs Traditional %diff, ± CL	(ES, ± CL)	Control vs Progressive %diff, ± CL	(ES, ± CL)	Traditional vs Progressive %diff, ± CL	(ES, ± CL)
5m (s)	All	0.4, ± 2.1	(0.07, ± 0.35)	0.2, ± 1.9	(0.03, ± 0.27)	0.0, ± 1.9	(0.00, ± 0.27)
	Pre-PHV	1.0, ± 9.9	(0.23, ± 2.14)	-5.3, ± 11.1	(-0.90, ± 1.75)	-6.2, ± 5.4	(-1.14, ± 0.94)
	Circa-PHV	-0.8, ± 3.7	(-0.10, ± 0.46)	0.1, ± 2.7	(0.02, ± 0.40)	-0.8, ± 3.7	(-0.10, ± 0.56)
	Post-PHV	0.5, ± 2.7	(0.12, ± 0.59)	1.6, ± 2.8	(0.23, ± 0.39)	1.1, ± 2.3	(0.16, ± 0.33)
10m (s)	All	-0.9, ± 2.5	(-0.14, ± 0.45)	-0.2, ± 2.4	(-0.03, ± 0.33)	0.5, ± 2.8	(0.07, ± 0.37)
	Pre-PHV	0.0, ± 6.2	(0.00, ± 1.30)	-3.1, ± 6.0	(-0.51, ± 0.95)	-3.1, ± 3.6	(-0.53, ± 0.60)
	Circa-PHV	-0.4, ± 3.5	(-0.05, ± 0.42)	-1.6, ± 4.7	(-0.24, ± 0.69)	-0.4, ± 3.5	(-0.05, ± 0.74)
	Post-PHV	-1.2, ± 3.0	(-0.26, ± 0.65)	1.5, ± 2.2	(0.20, ± 0.29)	2.7, ± 3.0	(0.38, ± 0.43)
20m (s)	All	0.4, ± 1.5	(0.06, ± 0.21)	1.0, ± 1.8	(0.12, ± 0.21)	0.9, ± 1.8	(0.11, ± 0.21)
	Pre-PHV	-0.9, ± 4.8	(-0.14, ± 0.75)	-3.5, ± 4.7	(-0.49, ± 0.63)	-2.9, ± 4.2	(-0.11, ± 0.15)
	Circa-PHV	-0.9, ± 3.6	(-0.10, ± 0.39)	0.7, ± 2.0	(0.09, ± 0.28)	-0.9, ± 3.6	(-0.10, ± 0.45)
	Post-PHV	0.4, ± 1.8	(0.07, ± 0.33)	1.7, ± 2.3	(0.21, ± 0.27)	1.3, ± 2.2	(0.17, ± 0.27)

Note: %diff = percentage difference in means; CL = 90% confidence limits; ES = effect size;

Table 8: Percentage difference (90%CL) in jump change scores within maturation groups and between training groups

Metric	Maturation	Control vs Traditional		Control vs Progressive		Traditional vs Progressive	
		%diff, ± CL	(ES, ± CL)	%diff, ± CL	(ES, ± CL)	%diff, ± CL	(ES, ± CL)
HJD	All	-1.4, ± 3.8	(-0.11, ± 0.29)	0.8, ± 3.6	(0.05, ± 0.23)	1.1, ± 2.9	(0.08, ± 0.21)
	Pre-PHV	2.6, ± 8.1	(0.25, ± 0.76)	5.7, ± 10.6	(0.47, ± 0.86)	3.0, ± 11.2	(0.25, ± 0.90)
	Circa-PHV	4.8, ± 6.3	(0.31, ± 0.40)	0.4, ± 6.2	(0.02, ± 0.39)	-4.2, ± 6.3	(-0.32, ± 0.45)
	Post-PHV	-4.8, ± 6.3	(-0.46, ± 0.57)	-2.5, ± 6.1	(-0.16, ± 0.37)	2.4, ± 3.4	(0.17, ± 0.27)
HJND	All	-1.6, ± 3.8	(-0.11, ± 0.27)	1.6, ± 3.3	(0.09, ± 0.20)	1.8, ± 3.1	(0.12, ± 0.21)
	Pre-PHV	0.0, ± 11.0	(0.00, ± 0.97)	6.4, ± 11.1	(0.63, ± 1.07)	6.4, ± 8.7	(0.59, ± 0.79)
	Circa-PHV	5.4, ± 8.8	(0.32, ± 0.51)	2.9, ± 6.8	(0.18, ± 0.40)	-2.3, ± 9.5	(-0.17, ± 0.64)
	Post-PHV	-4.3, ± 7.0	(-0.40, ± 0.62)	-2.1, ± 6.8	(-0.12, ± 0.37)	2.3, ± 3.5	(0.15, ± 0.23)
TJ Score	All	9.6, ± 16.6	(1.35, ± 0.58)	22.8, ± 15.1	(0.86, ± 0.59)*	7.7, ± 13.2	(0.27, ± 0.45)
	Pre-PHV	5.4, ± 78.4	(0.32, ± 3.50)	49.0, ± 94.0	(1.77, ± 2.95)	41.3, ± 50.3	(2.79, ± 3.29)
	Circa-PHV	25.4, ± 31.5	(1.14, ± 1.39)	20.9, ± 24.4	(0.77, ± 0.88)	-3.5, ± 34.7	(-0.13, ± 1.04)
	Post-PHV	6.3, ± 37.7	(0.19, ± 1.02)	9.9, ± 37.5	(0.35, ± 1.19)	3.3, ± 15.0	(0.11, ± 0.47)

Note: * = significant difference between training groups (p<0.05); %diff = percentage difference in means; CL = 90% confidence limits; ES = effect size; HJD = Horizontal jump dominant leg; HJND = Horizontal jump non-dominant leg

Discussion

The purpose of this study was to compare the effects of a progressive and traditional coaching style on sprint and jump performance within varying levels of maturation. Previous literature informed the hypothesis that the progressive-group would elicit the greatest sprint and jump improvements for the pre and post-PHV groups, in conjunction with a decrease in injury markers. Based on the phenomenon termed 'adolescent awkwardness', the circa-PHV group was hypothesised to respond best to the traditional style of coaching; whilst enjoyment would be consistent between traditional and progressive groups regardless of maturation. As hypothesised, the results of this study revealed that although non-significant (p>0.05), different coaching modalities may elicit superior improvements in sprint and jump performances if delivered to those of the appropriate physical and neurological age. It was also identified that movements requiring high force generation may correspond with a heightened risk of injury.

The effects of progressive and traditional coaching strategies on pre-PHV groups:

The progressive coaching style promoted the greatest improvements in pre-PHV 5m, 10m, and 20m sprint times, and both horizontal jump performances when compared to the traditional and control groups. This indicates this method of coaching may in fact benefit the pre-PHV maturation-group more-so than other styles if performance is the desired outcome. This finding supports both the hypothesis of the current study and relevant literature surrounding the underlying methods incorporated within the progressive coaching style (Chambers & Vickers, 2006; Light, 2004; Rucci & Tomporowski, 2010; Zeng et al., 2016). A meta-analysis completed by Moran et al., (2016), investigated sprint enhancement with respect to maturation and describes how improvements in pre-PHV sprint performances are typically restricted due to the limitations surrounding muscular strength, neuromuscular control and anthropometric factors. The current study produced dissimilar findings to these, and although results are non-significant, suggest appropriate coaching strategies may produce viable sprint training opportunities within the pre-PHV population. The disparities between the meta-analysis performed by Moran et al., (2016) and the current study lie within the style of intervention, and the population tested. Inclusion for Moran et al., (2016), required sprinting-based movements with a specific recovery period and utilised participants who were engaged in organised sport. In contrast, the current study used sub-maximal fundamental sprint mechanics as the training intervention aimed at altering technique, within a general population of individuals. These factors may be critical in identifying when and how to target sprint training within the pre-PHV population.

When investigating the mechanisms behind the sprint improvements, previous research has identified that improved sprint times involve increases in step length and/or step frequency without negatively effecting the other (Hunter, Marshall, & McNair, 2004b; Salo, Bezodis, Batterham, & Kerwin, 2011). Kinematic analysis of the pre-PHV progressive group means supported these statements as increases ($p>0.05$) in step length were evident, with little variation in step frequency when compared to pre-test measures (see Appendix 3). Previous literature has linked a longer step length to increases in standing height and limb length (Ford et al., 2011; Meyers, 2016; Oliver & Rumpf, 2014), both of which increased significantly ($p<0.05$) within all the pre-PHV groups over the period of the intervention. These anthropometric variations begin to provide a plausible mechanism for the altered kinematics; however, it is important to note the traditional and control groups also exhibited these anthropometric trends, but unlike the progressive group, these did not transpire to improved step length and/or frequency. This conclusion acknowledges the plausibility of the successful application of the progressive coaching sessions, which focussed on key sprint mechanics and movement efficiency (Appendix 2) ultimately refining and synchronising movement patterns more-so than the traditional or control groups (Cissik, 2005a, 2005b; Moran, Sandercock, Rumpf, & Parry, 2016). The ability to coordinate the sequencing of multiple limb segments, synchronise motor unit recruitment, and increase the number of motor units utilised, has been shown to produce greater muscular force output (Seagrave et al., 2009; Young, 2006). These physiological and neural adaptations can be gained through muscular overload and high velocity muscular activation (Jung, 2003; McBride, Triplett-McBride, Davie, & Newton, 2002), with the latter a specific element included in the training programmes utilised within this study. Supporting this hypothesis, the HJD and HJND displayed significant increases in jump distance, which illustrates a likely increase in lower limb power (Chelly et al., 2010; Cronin

& Hansen, 2005; Hopkins, Schabort, & Hawley, 2001), which has been shown to be an important factor in improving sprint performance (Comfort, Haigh, & Matthews, 2012; Murtagh et al., 2017). It is unwise to state that improved lower limb power via neural activation, or neuromuscular adaptation, is a leading cause of performance and kinematic improvements in the current study due to the lack of specific measurements of these variables; however, due to the short duration and power-based tests performed, it is a conclusion worth considering.

This notion of increased muscular output is further supported by the findings in the pre-PHV tuck jump scores, which showed the largest decrement in the progressive group, suggesting they have an increased risk of injury post-intervention. The need to safely control and decelerate limbs via eccentric contractions is vital to injury management, and can be exasperated during periods of increased force production (Davies, Riemann, & Manske, 2015; Yetter & Moir, 2008). This process requires an element of technical control and muscular strength, neither of which were targeted within the coaching sessions of this intervention. These findings suggest the improvements in sprint and jump performances witnessed within the pre-PHV group were accompanied by a decreased ability to safely control the underlying mechanisms responsible for these improvements. This finding is critical in the long term safety of athletes, as previous research has already identified a higher injury rate for individuals around the period of PHV (Cane et al., 2008; Kemper et al., 2015; Van Der Sluis et al., 2015, 2014). Future interventions pursuing sprint and jump improvements should consider eccentric, plyometric and/or other strengthening interventions to supplement their sprint and jumps training to not only increase the performance response, but to provide the technical and physical proficiency required to safely accommodate the physiological changes that occur during this process (Cronin & Hansen, 2005; Izquierdo et al., 2009; Radnor et al., 2017).

The effects of progressive and traditional coaching strategies on circa-PHV groups:

Based on the data collected it is ill-advised to state the circa-PHV group responded more effectively to any one of the training methods utilised within this study, therefore proving the initial hypothesis to be incorrect. Despite the lack of significant findings, the circa-PHV traditional group displayed the greatest improvements in 5m and 20m sprint times, as well as both the horizontal jump distances. This trend may begin to reveal an underlying need to adjust coaching strategies between levels of maturation. The traditional approach incorporated direct, individual feedback, as opposed to the previously successful questioning and problem-solving methods used within the progressive style of coaching (Chambers & Vickers, 2006; Light, 2004; Rucci & Tomporowski, 2010; Zeng et al., 2016). The poorly understood, yet frequently acknowledged phenomenon termed adolescent awkwardness (P. Ford et al., 2011; Oliver, Lloyd, & Rumpf, 2013; Philippaerts et al., 2006), may be influential in explaining why the traditional training was successful within the circa-PHV population. Adolescent awkwardness occurs during the adolescent growth phase and is characterised by rapid long-bone growth prior to muscular development which may correspond with a period of disruption in motor coordination (Lloyd et al., 2009; Oliver et al., 2013). Clear, direct, and individual instructions such as those utilised in the traditional coaching method, may help to produce a more effective movement output (Marchant, Greig, & Scott, 2009; Wulf, McNevin, Tollner, & Mercer, 2004), or minimise the supposed disconnect between the brain and body during the adolescent growth spurt more-so than the strategies observed within the progressive coaching style.

When analysing sprint metrics, all circa-groups improved each of the 5m, 10m and 20m sprint times, albeit insignificantly for the majority (see Table 7). Kinematic variables associated with these sprint performances show the traditional and control groups displaying non-significant ($p>0.05$) increases in most step length and step frequency measures, which supports the findings of past sprint literature (Hunter et al., 2004; Salo et al., 2011; Standing & Maulder, 2017). This tendency proved inconsistent within the progressive group who increased step length in all measured ground contacts, but also saw a decrease in step frequency throughout. These discoveries propose this decrease in step frequency was not enough to inversely effect the performance gains achieved through the increased step length, or inform that there were other factors at play outside of this studies measured variables (Cronin, Hansen, Kawamori, & McNair, 2008; Salo et al., 2011). As discussed, the kinematic variations across groups are likely influenced by the significant increases ($p<0.05$) in standing height, weight and seated height observed for all the circa-PHV groups as a natural response of maturation (Ford et al., 2011, Meyers, 2016; Oliver, & Rumpf, 2014). It is important to acknowledge there are likely factors external to the study design that were influential to sprint results within this population. It is hypothesised that varying levels of cognitive focus, fatigue and motivation (Marcora et al., 2009; Moreno, González-cutre, Martín-albo, & Cervelló, 2010), movement experience gained through incidental exercise or regular physical education classes, or neuromuscular maturation may have influenced overall findings (Asadi et al., 2018; Rodriguez-Rosell et al., 2015).

As observed within the pre-PHV findings, the training approach that generated the greatest sprint and jump improvements within the circa-PHV population, also produced the greatest increase in injury markers during the tuck jump assessment. This trend has been hypothesised to be attributed to increases in concentric power, segment sequencing and/or the inability to accommodate the increases in these physiological alterations. To counter these initial statements, the control group improved their tuck jump score by 8.9%, which implies they are at a decreased risk of injury than their pre-test; however, they also improved each of their sprint times, which suggests the mechanism behind these variations is still unclear and requires further investigation. It is recommended this test is utilised with caution until the underlying causes of these changes are identified within this population (Read et al., 2017).

The effects of progressive and traditional coaching strategies on post-PHV groups:

As discussed previously, the lack of significant group differences within maturation suggests minimal differences between coaching strategies and sprint performances. Despite this, the control post-PHV group elicited the greatest improvements in 5m and 20m sprint times, as well as both horizontal jump distances and tuck jump scores. These results counter the initial hypothesis of this paper and suggest neither of the training groups were able to generate performance benefits greater than those achieved through natural maturation, rendering the training intervention ineffective within this population. Biological maturation within the post-PHV includes hormonal, physical, neurological and physiological adaptations that result in a greater muscle mass, increased long bone length, and neural enhancement which lead to natural improvements in some motor tasks

(Ford et al., 2011; Meyers, 2016) and also sprint performance (Moran et al., 2016). These statements are supported by control groups producing comparable improvements in sprint performances to those observed in both training groups, accompanied by significant increases (p<0.05) in standing height and weight. Despite these increases, step length and step frequency displayed irregular but similar changes through all training and control groups; therefore, suggesting their influence on sprint performance was limited within this cohort (Hunter et al., 2004; Salo et al., 2011; Standing & Maulder, 2017). Probable justifications for these increases in sprint times and horizontal jump performances include refined neuromuscular coordination, increases in muscular output and/or greater mechanical efficiency (Seagrave et al., 2009; Young, 2006), although without direct measures of these variables it is difficult to conclude.

Based on the findings of the current study, technical training utilising traditional or progressive coaching methods is not sufficient to elicit responses greater than those achieved through natural maturation, and therefore trainers and coaches working with individuals of post-PHV maturation should employ appropriate physical interventions alongside technical training of various nature to maximise motor improvements. As per the recommendations of Lloyd, Radnor, De Ste Croix, Cronin, and Oliver, (2015) and Rodriguez-Rosell et al., (2015), interventions targeting plyometric and resistance training exercises may elicit responses within the post-PHV maturation group than movement-based coaching alone. It is important to note coaches working with adolescent athletes need to acknowledge the impact of physical and neurological maturation when comparing performances, or pre/post testing in sporting contexts, especially if it is to provide a measure of training effectiveness for new athletes as these improvements may in fact be due to natural maturation and not as a consequence of training strategies.

Collective group findings

When comparing training groups within maturation levels, there were no significant differences (p<0.05) in pre/post change scores between training groups and control groups. It is hypothesised these findings may be due to the lack of statistical power from low participant numbers within the pre-PHV group and the overall variance witnessed due to the general population utilised within this study.

As hypothesised, enjoyment played a limited role when it came to training group selection, as results proved there were no significant differences (p>0.05) within maturation levels. Mean scores ranged from 49.7 to 61.4 points (out of a maximum of 80), suggesting that there was an adequate level of enjoyment through each training modality; therefore, over a five-week period either strategy is appropriate from an enjoyment perspective and performance gains will provide justification for using one approach over the other.

Limitations and future recommendations

Primary limitations of this study include low participant numbers within the pre-PHV groups. This was due to the age of the high school students utilised and the need to break a small pre-PHV cohort into three different experimental groups. Despite this, training groups within pre-PHV maturation were of similar size, allowing a more consistent statistical approach to be applied. Future research should utilise a slightly younger cohort to provide greater pre-PHV numbers and improve the statistical strength of the analysis. Secondly, the PHV equation used to separate maturation groups as presented by Mirwald et al., (2002), has had a reported variance of ± 0.592yrs (Meyers et al., 2017). These findings suggest those individuals who are within this acknowledged range could be wrongfully grouped, ultimately decreasing the clarity of results and likely effecting the significance of findings. Future recommendations regarding this concept include utilising a greater diversity of ages to provide a more distinct maturational difference between groups. It is also suggested training studies aiming to improve sprint performance through muscular and neural enhancements, should incorporate protective elements to allow the safe dissipation of forces and eccentric control required to accommodate any power developments. Future recommendations would also suggest the quantification of extra-curricular exercise, physical education classes and sports trainings in order to help clarify the differences between training adaptations, and those gained as a natural consequence of biological maturation.

Conclusion

A summary of the findings from the current study has revealed a variety of aspects worthy of consideration when implementing intervention and coaching strategies across various levels of maturation. The use of a progressive coaching style incorporating elements of problem solving, competition, group interaction and guided feedback has shown to be more effective for individuals within the pre-PHV growth-phase. This was inconsistent between maturation levels, as the circa-PHV responded more effectively to the traditional coaching style that incorporated direct individual feedback focussing on repetition and self-improvement, likely influenced by the impact of adolescent awkwardness. Finally, the post-PHV group showed a less-effective response to the training groups than they did to the natural benefits gained throughout natural biological maturation in the control group. These findings suggest that varying levels of biological maturation may require the use of unique coaching strategies in order to prompt the most effective outcomes from training programmes being implemented. Final recommendations of this study include the need for strengthening exercises to help decrease the risk of injury encountered within movements requiring repetitive high force outputs. This could be pursued through resistance training or plyometric interventions, or possibly through movement-based coaching strategies. With the lack of significant differences between groups, accompanied with sprint and jump performance improvements throughout maturation levels and training groups, it is recommended that a variety of coaching methods be used to target individual learning styles if a movement-based sprint intervention is being implemented. It is also imperative to re-iterate that natural improvements in movement-based activities are likely during biological maturation, and coaches working with these athletes need to acknowledge these when quantifying the effectiveness of any training interventions.

CHAPTER 4: THESIS DISCUSSION

The purpose of this thesis was to identify and describe physical, injury and performance-based differences between maturational groups within a general school-based population of youth; and then utilising these findings to identify the most effective coaching strategies to maximise learning and motor performances within this population. The outcome of this thesis hoped to inform practitioners as to how they can maximise learning and adaptation from their programmes through meaningful and purposeful coaching methods.

A summary of Chapter 2, which investigated the anthropometric and performance measures associated with each level of biological maturation (pre, circa, post), revealed significant differences between groups for both categories of variables. Supporting the findings of previous literature, standing height, seated height and weight increased significantly ($p<0.05$) between pre, circa and post groups. These increases have been linked to the timing of peak height velocity (PHV) and have a contributory effect on the improvements in the corresponding sprint and jump performance metrics observed between levels of maturation (Ford et al., 2011; Meyers, 2016). Underlying mechanisms for these improvements may include kinematic alterations due to differences in limb length (Ford et al., 2011; Meyers, 2016), increased force output through greater muscular development (Asadi et al., 2018) and neural maturation (Oliver & Rumpf, 2014). Within-group variability was greatest within the circa maturation group, suggesting they have a larger range of movement presentation, possibly due to the intensified growth rates and suggested neuromuscular disconnect that can effect this maturation group (Lloyd et al., 2009; Lloyd & Oliver, 2012). The findings of Chapter 2 supported the notion that within the population tested, there were clear differences in anthropometrics, performance capabilities and therefore it was hypothesised that the neurological adaptations that have been shown to occur through maturation (De Bellis, 2001; Huttenlocher, 1979; Yakovlev & LeCours, 1967), may also have a role to play in optimising performance. It also displayed the need to consider the impact of adolescent awkwardness within the circa-PHV population, as the variability in this population was evident and would likely impact on motor skill performance. These findings were of extreme value when preparing the methodology for Chapter 3, as the neurological and performance-based differences observed, highlighted the need for varying stimulation, training and therefore coaching methods to be trialled to identify the most effective strategies within each maturation level.

The aim of Chapter 3 was to implement varying coaching strategies in an attempt to identify which, if any, would elicit the greatest improvements in sprint and jump performance across maturation levels. Results revealed each of the three levels of maturation responded more effectively to a different method of coaching, although differences between training groups were non-significant ($p>0.05$). Progressive pre-PHV group means displayed improvements in all sprint and jump times, greater than those within the traditional or control groups, whilst the traditional coaching strategy displayed a similar dominance within the circa maturation level. The post-PHV results suggested both training groups elicited a lesser response than those observed through natural improvements within the control group. Interestingly, when performances were most improved via the progressive or traditional coaching (as seen in the pre and circa-PHV groups), the risk of injury also displayed the largest increase. There are various mechanisms suggested to support, or contest these findings, some of which include anthropometric increases during the intervention (Ford et al., 2011; Meyers, 2016), improved neural synchronisation (Cissik, 2005a, 2005b), increased power output (Seagrave et al., 2009; Young, 2006), a lack of eccentric strength (Davies et al., 2015; Yetter & Moir, 2008), or other elements outside the control of this study design. These findings justify the need to consider varying coaching styles between maturation groups, and therefore help answer the second aim of this thesis.

Collectively, these studies aimed to firstly identify differences in physical, injury, and performance-based measures within different levels of biological maturation. Chapter 2 has directly accomplished this task and provided critical insight into how and where these differences lie. These findings then further informed the methodology of Chapter 3 aimed at identifying which, if any, coaching strategy was more effective in improving sprint and jump performance, as well as minimising injury markers. The findings of Chapter 3 have achieved the objective and allowed the first steps to be taken into understanding how training programmes are best utilised within varying levels of biological maturation. Overall, these thesis findings inform practitioners within this field of the methods of coaching that may be implemented to supplement the programmes they administer, with the hope of improving the performance outcomes gained. The results have displayed trends and highlighted key variables of interest that support the need to consider coaching styles and strategies when working within a youth setting, therefore, achieving both the primary the secondary purposes of this study.

Practical applications

Collective findings of this thesis provide several key outcomes that can be implemented across multiple sport science disciplines. Anthropometric findings showing the significant differences between maturation levels further implies the need to adopt coaching strategies to allow all youth to participate effectively in sport and exercise, especially as these variations are not synonymous with chronological age. Drills, activities and exercises need to provide progressions and regressions to allow those of different body sizes to maintain a level of optimal challenge without the need to conform to one setup.

Matching the increases in maturational growth, were the sprint and jump performance values, suggesting increased maturation corresponds with an improved performance. This is often evident within team sports which include those of the same chronological age but have large disparities in biological maturation. Identifying and catering to these variations in ability is critical in maintaining participation in sports long term. This factor should also be considered when assessing the effectiveness of training programmes with youth in and around PHV, as results have shown that natural improvements in performance can occur due to physical and physiological maturation, and these may be confused with results gained through training.

Finally, a key application of this thesis is that different maturation groups may respond better to a certain coaching strategy, without effecting the enjoyment of the participants. This can have implications on the effectiveness of training programmes and the ability of the coach/trainer to maximise the learning and adaptation within a cohort of youth individuals. Until future research can further refine these methods and help explain the underlying mechanisms behind the observed changes, it is suggested that coaches employ a range of coaching strategies in order to cater to all learning styles within a cohort.

Thesis limitations

A key factor within this thesis is the ability to group individuals by maturation. Common practise within current youth literature is to utilise the non-invasive equation proposed by Mirwald et al., (2002), despite the equation having a reported variance of ± 0.592yrs (Meyers, Oliver, Hughes, Lloyd, & Cronin, 2017). These findings suggest those individuals who are within this range could be wrongfully grouped, ultimately decreasing the clarity of results and likely effecting the significance of findings. The key factor to consider is that when comparing the findings of this study to previous literature, the vast majority have also utilised this equation, hence allowing comparable conclusions to be made throughout.

Another notable limitation of this thesis is the number of individuals within the pre-PHV groups of Chapter 3. Due to the cohort tested, there were limited numbers of pre-PHV individuals before having them split into the three intervention groups. This meant small group numbers of three and four were used; however, this limitation could not be accounted for based on the high-school nature of the cohort.

Enjoyment was a factor that was required to provide a parallel view of what performance data displayed, especially when longevity on the sport is of importance. Although both training groups in Chapter 3 identified no significant differences between coaching styles, it is suggested that the five-week (semi-acute) nature of the intervention may have played a role in this. Coaching seasons often last several months, and sometimes even longer. With the excitement of external coaches and a new-sprint programme, it is not surprising that enjoyment was high in both groups within the schooling setting. It is suggested a more accurate measure of enjoyment would have been to complete these methods over a longer period of time to allow the novel-ness of the intervention to dissipate.

Finally, a true representation of adaptation and learning is the legitimacy of skill performance over time. It would have been of benefit to the study to incorporate a final testing session two weeks post completion of the intervention to assess retention of cues, performance benefits and key mechanical variables within the cohort. This would supply information into how the observed changes manifested, and how successful these teachings were on a grander scale.

Future research

Supplementary research in this field should aim to quantify both ground reaction forces and measures of neural output (motor unit recruitment and synchronisation), as to help communicate the underlying mechanisms to sprint improvements within the youth setting. It is also suggested that future research obtains participants of a broader age range to create a distinct biological age difference between groups to provide a clearer picture of maturational differences. In regard to participant longevity, it is suggested training studies aiming to improve sprint performance through muscular and neural enhancements should incorporate elements to allow the safe dissipation of forces and increase eccentric control required to accommodate any power developments. Finally, to build on this coaching-based methodology, it is recommended future research investigates the impact of a plyometric or resistance training regime delivered in various coaching styles in order to try and maximise the responses by youth athletes. This should also be accompanied by a questionnaire or quantification of external exercise to allow accurate conclusions to be made about the origin of any improvements.

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Appendices

Appendix 1: Institute ethics approval

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19 June 2017

Centre for Sport Science and Human Performance
Regan Standing

Dear Regan,

HUMAN ETHICS RESEARCH APPLICATION

Title: Effects of qualitative feedback on linear running performance in youth

Thank you for you application which was considered by the Human Ethics in Research Group on 15 June 2017. It is with pleasure I advise ethics approval for your project is granted.

Ethical approval is granted until 31 December 2017 or until the project has been completed, whichever comes first.

Please note that should there be any changes to the approved research project then it will need to be referred back to the committee for further consideration.

The Human Ethics in Research Group wishes you every success with this project.

Kind regards

Megan Allardice
pp Elizabeth Bang
Chairperson
Wintec Human Ethics in Research Group

Cc. Peter Maulder, Supervisor

Appendix 2: Training session plans

<u>Session 1 = Posture and body position (40mins)</u>

Traditional session plan – Coach 1

Session component	Key outcomes	Activities / drills	Teaching points
Warm up and intro (10mins)	To prepare subjects for exercise, both physically and mentally	- Run gym length x8 **– Individual** - Hamstring sweeps x20m - Lunges (pelvic push) + rotate + stand and glut hold (40m total) - Drills – Recap on week before (2-3 x 20m) - Dynamic stretches leg swings (f/b & s/s) Calf pumps - Grapevines x20m each way - Stride outs (70-80-90%)	• This is to be consistent throughout each session • Warm-up is always **coach led** • Technical advice **is given** to correct any technical errors
Body of session (25mins)	To cover key postural aspects associated with sprinting such as; core stabilisation, postural positioning and vertical alignment (no sway)	<u>General</u> **1) Standing still, displaying good posture** Them to show straight line of head, back and butt. *Using helium balloons (rise to the sky), or piece of string analogy (pulling you towards the roof), being 'big dawgs'* **2) Small bounces with leg up and good posture – 10m each leg, then 10m with a 3 bounce and change** Remaining <u>tight</u> and <u>controlled</u>, ground leg doing work. *Stay tall being the cue (push through floor)* **3) 20m strides with same posture (x2)** Put posture drills into place in sprint scenario. How good can you transfer this skill? – Challenge. *No side to side (washing machines)* <u>Acceleration</u>	• Fun and inclusive • **Individual drills and feedback** • **Feedback TOLD and athlete not questioned** • Mix of internal and external cues • Drills to be demonstrated and told at same time. Get them to how before starting Celebrate success with high fives with coach. Give

		4) Standing hip position demonstration *Don't want to be bootylicious (too much out the back), don't want to be a creeper (too much in the front), want to remain neutral* **5) March with focus on neutral hips and stable core, straight trunk (x3)** Be robots, make the noise, robots can only move in certain places **6) Lean on hall and drive with forward lean and straight posture (20s x 3)** Legs are like pistons in a car, up and down, trying to push through the wall (posture main focus) <u>Transition</u> **7) High knees running, focus on core and high hips (not leaning back) – slight lean forward (10m x3)** Like your in a dream trying to run away but are too slow, posture, hips and piston legs from previous drills **8) High knees into stride out (keep hips up – don't sit) 10m x3** Sleeping dream, then you turn into Usain Bolt, but don't drop hips and turn into a charging bull (dropping hips), *(pulled towards sky, remain neutral)* **9) Stride-outs 3x20m showing what they have learnt, putting it all together** Posture (straight line), neutral hips, setup position first on start line, rate out of 10	feedback one on one to promote more individual environment
Cool down and recap of key points (5mins)		Release muscle tension and recap on session	• **Coach led**

Progressive session plan - Coach 2

Session component	Key outcomes	Activities / drills	Teaching points
Warm up	To prepare subjects for exercise, both physically and mentally	- Run gym length x8 **– GROUP** - Hamstring sweeps x20m - Lunges (pelvic push) + rotate + stand and glut hold (40m total) - Drills – Recap on week before (2-3 x 20m) - Dynamic stretches leg swings (f/b & s/s) Calf pumps - Grapevines x20m each way - Stride outs (70-80-90%)	• This is to be consistent throughout each session • Warm-up is **coach led with athlete input** • Technical advice is given to correct any technical errors but questioning included
Body of session		<u>General</u> **1) Standing still, displaying good posture** Question them around what body parts we want to have inline (head back and butt). *Using helium balloons, or piece of string analogy, shoulders back being 'big dawgs'.* **2) Small bounces with leg up and good posture 10m each leg, then 10m with a 3 bounce and change** As a team, all at same time staying in a line. Remaining tight and controlled, ground leg doing work. *Stay tall being the cue* **3) 20m strides with same posture (x2)** Put posture drills into place in sprint scenario. How good can you transfer this skill? – Challenge. *No side to side (washing machines)*. Get partner to rate your posture – thumbometer. <u>Acceleration</u> **4) Standing hip position demonstration** *Don't want to be bootylicious (too much out the back), don't want to be a creeper (too much in the front), want to remain neutral* **5) March with focus on neutral hips and stable core, straight trunk (x3)**	• Fun and inclusive • **Individual AND group drills** • **Problem solving included** • **Feedback told but athlete questioned** • Mix of internal and external cues • Drills to be demonstrated and told at same time. Get them to how before starting Celebrate success by high fives with team. Also pull in for group huddles –

		Be robots, make the noise, robots can only move in certain places. Robot conga-line follow the leader. Must stay in time **6) Lean on partner and drive showing forward lean and straight posture, partner moves slowly (10m x 3)** Legs are like pistons in a car, up and down, trying to push through the wall (posture main focus) – trust in partner Transition **7) High knees running, focus on core and not dropping hips (not leaning back) – slight lean forward 10m x3** Like your in a dream trying to run away but are too slow, posture, hips and piston legs from previous drills **8) Partner races - high knees into stride out (don't drop hips) 10m x3, DQ'ed if we see dropped hips** Sleeping dream, then you turn into Usain Bolt, but don't drop hips and turn into a charging bull (dropping hips) – call 'go' when all are doing high knees then they run **9) Stride-outs 3x20m showing what they have learnt, putting it all together** Posture (straight line), neutral hips, setup position first on start line. Ask questions about what they thought, how to improve	emphasises group environment more
Cool down and recap of key points		Release muscle tension and recap on session	• Coach and athlete led, get them to take charge and demonstrate

<u>Session 2 = Arms (50mins)</u>
Traditional session plan – Coach 2
Session focus = To improve arm drive and force application

Session component	**Key outcomes**	**Activities / drills**	**Teaching points**
Warm up and intro (15mins)	To prepare subjects for exercise, both physically and mentally	- **Recap on cues from week before – want to see them in all drills today** - Run gym length x8 **– Individual** - Hamstring sweeps x20m - Lunges (pelvic push) + rotate + stand and glut hold (40m total) - Dynamic stretches leg swings (f/b & s/s) Calf pumps - Grapevines x20m each way - Stride outs (70-80-90%)	• This is to be consistent throughout each session • Warm-up is always **coach led** • Technical advice **is given** to correct any technical errors
Body of session (25mins)	To cover key aspects associated with arm sequencing and arm movements	**1) No arm seated jumps – arm facilitated seated jumps** - Sit on floor with legs out in front. Cross arms on chest and try to get them to jump up off ground without moving arms (its really hard) - Then do the same and get them to use arm drive (makes things easier) (Discuss how using our arms when running produces more force and makes us go faster) **2) Standing long arm swings** - Standing up, swinging straight arms, feeling the shoulder joint move not the elbow Make sure relaxed at neck and shoulders **3) Sitting on ground with arms at 90 degrees – <u>chip to lip</u>** - Swinging arms at 90 or you hit floor – all in shoulder joint again, Posture!!! Begin slow and speed up to try and get some lift Now move closer to each other – must keep elbows in close (Discuss how it is the aggressive back drive of arm that we want – transfers to a fast down drive of foot) **4) Kneeling in split stance** – **Simon says** - same focus (<u>chip to lip)</u>	• Fun and inclusive • **Individual drills and feedback** • **Feedback TOLD and athlete not questioned** • Mix of internal and external cues • Drills to be demonstrated and told at same time. Get them to how before starting

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<td>- Include postural cues, Number of arm swings , hips etc
- no side to side sway (washing machines) – loses linear force

5) Then standing in acceleration angle with split stance (45 degrees)
- Pumping arms from shoulders, INCLUDE straight line posture from floor to head

6) Stride outs x2 - with arm and posture focus – feedback from coach

7) Marching 2x10m
Like last week, marches with posture and arms! Control the movement
(Watch straightening of arms – keep at 90)

8) High knees 2x30 contacts
Focus on fast hands and posture – clap out the tempo for them increasing speed

9) Long, short and no arm strides
- Do a stride out with no arms (tight behind back)
- Do a stride out with long slow arm movements
- Do a stride out with short fast movements

(Discuss the impact these arm movements had on their legs – caused legs to be long/slow etc)

10) Stride out x3 , with aggressive backwards drive of arms FOR SPEED with feedback about posture and arms

11) Autobots and Decepticons (cause we are transforming them) – alternate start position

- Focus on posture and arms, killed if they get caught or lose form
Yell one groups name and they race</td>
<td>Celebrate success with high fives with coach. Give feedback one on one to promote more individual environment</td>
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<td>Cool down and recap of key points (5mins)</td>
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<td>Release muscle tension and recap on session</td>
<td>• Coach led</td>
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Progressive session plan - Coach 1
Session focus = To improve arm drive and force application

Session component	Key outcomes	Activities / drills	Teaching points
Warm up (15mins)	To prepare subjects for exercise, both physically and mentally	- **Question on cues from last week – want to see this in all drills** - Run gym length x8 **– GROUP** - Hamstring sweeps x20m - Lunges (pelvic push) + rotate + stand and glut hold (40m total) - Dynamic stretches leg swings (f/b & s/s) Calf pumps - Grapevines x20m each way - Stride outs (70-80-90%)	• This is to be consistent throughout each session • Warm-up is **coach led with athlete input** • Technical advice is given to correct any technical errors but questioning included
Body of session (25mins)	To cover key aspects associated with arm sequencing and arm movements	1) **Stand up task no hands** - Sit by yourself, arms folds and legs in front. Without moving arms stand up. - You have become one – TRANSFORMERS = Groups of 5-6, back to back and link arms, stand up. – Name you transformer!! And choose Autobots or Decepticons (Discuss how using our arms when running produces more force and makes us go faster) 2) **Standing long arm swings** All together in time!!!! - Standing up, swinging straight arms, feeling the shoulder joint move not the elbow Make sure relaxed at neck and shoulders 3) **Sitting on ground with arms at 90 degrees – chip to lip** - Swinging arms at 90 or you hit floor – all in shoulder joint again, Posture!!! Begin slow and speed up to try and get some lift Now move closer to each other (Transformer teams) – must keep elbows in close (Discuss how it is the aggressive back drive of arm that we want – transfers to a fast down drive of foot)	• Fun and inclusive • **Individual AND group drills** • **Problem solving included** • **Feedback told but athlete questioned** • Mix of internal and external cues • Drills to be demonstrated and told at same time. Get them to how before starting

		4) Kneeling in split stance – **Simon says-** same focus (chip to lip) - Include postural cues, Number of arm swings , hips etc - No side to side sway (washing machines) – loses linear force **5) Then standing in acceleration angle with split stance (45 degrees)** - Pumping arms from shoulders, INCLUDE straight line posture from floor to head **6) Stride outs x2 -** with arm and posture focus Peer feedback – thumbometer from the side view **7) Marching 2x10m** Like last week, marches with posture and arms! Control the movement (Watch straightening of arms – keep at 90) **8) High knees 2x30 contacts** Focus on fast hands and posture together I will count out the tempo – clapping increasing speed **9) Long, short and no arm strides** - Do a stride out with no arms (tight behind back) - Do a stride out with long slow arm movements - Do a stride out with short fast movements (Discuss the impact these arm movements had on their legs – caused legs to be long/slow etc) **10) Stride out x3 ,** with aggressive backwards drive of arms FOR SPEED with feedback about posture and arms Autobots and Decepticons (cause we are transforming them) **11)** Autobots and Decepticons (cause we are transforming them) – alternate start position - Line up 2m from each other in two lines – call one and they chase. (First game or two they will probably lose arm focus) - Focus on posture and arms, killed if they get caught or lose form	Celebrate success by high fives with team. Also pull in for group huddles – emphasises group environment more
Cool down and recap of key points (5mins)		Release muscle tension and recap on session	• Coach and athlete led, get them to take charge and demonstrate

<u>Session 3 = High knees (45mins)</u>

Traditional session plan – Coach 1

Session focus = To improve knee height and overall sequencing

Session component	Key outcomes	Activities / drills	Teaching points
Warm up and intro (15mins)	To prepare subjects for exercise, both physically and mentally	- **Recap on cues from week before – want to see them in all drills today** - Run gym length x8 **– Individual** - Hamstring sweeps x20m - Lunges (pelvic push) + rotate + stand and glut hold (40m total) - Dynamic stretches leg swings (f/b & s/s) Calf pumps - Grapevines x20m each way - Stride outs (60-80-100%)	• This is to be consistent throughout each session • Warm-up is always **coach led** • Technical advice **is given** to correct any technical errors
Body of session (25mins)	To cover key aspects associated with knee drive	***1)*** **Skipping (moderate intensity) 3x20m total** *(show me your feminine side – kick boxers knee)* - Skipping with good posture, getting <u>knee up to 90</u> - Same again but this time get the <u>arms working</u> as well - Skip for height this time – <u>big knee drive</u> (control posture and coordinate arms) **2) 2 foot skip to single knee drive (with hop between) 20m** *(year 10s were way more coordinated last week!)* - Trying to coordinate unilateral and bilateral movements together <u>Focus being knee to 90, arms and posture</u> **3) High knees** - Knees up to hip height this time!!! **4) Stride outs x2** – (*Show me what you have learnt)* - Stride out once ensuring knee drive and aggressive arms Will probably all do weird slow high knee running – discuss how it needs to be fast and aggressive. Demonstrate theirs and then proper. - Get them to repeat stride out	• Fun and inclusive • **Individual drills and feedback** • **Feedback TOLD and athlete not questioned** • Mix of internal and external cues • Drills to be demonstrated and told at same time. Get them to how before starting

		5) Ladders – Sideways, 2 feet in each square x 4 (2x each side) - High knees moving laterally for speed (must get knees up, stay up tall!!) **6) Ladders – Front on x 3** - One foot in each for speed!!! - Knees must be up and aggressive arms **7) Hurdle running (1 or 2 feet apart) x2** *(Individual punishments for hitting hurdles)* - One foot between each hurdle, getting knees up high (posture and arms) - 2nd time is for speed **8) Hurdle running at increasing distances (actually running this time) x2** *(Individual punishments for hitting hurdles)* - One foot between each hurdle, getting knees up high, must move horizontally this time (posture and arms) DO NOT BECOME BOOTYLICIOUS **9) Stride out x3** - Keeping knees up high but driving aggressively. Spend some time here giving individual feedback on form (posture, arms or knees)	Celebrate success with high fives with coach. Give feedback one on one to promote more individual environment
Cool down and recap of key points (5mins)		Release muscle tension and recap on session Hand out forms!!!	• **Coach led**

Progressive session plan - Coach 2
Session focus = To improve knee height and overall sequencing

Session component	Key outcomes	Activities / drills	Teaching points
Warm up (15mins)	To prepare subjects for exercise, both physically and mentally	- **Question on cues from last week – want to see this in all drills** - Run gym length x8 **– GROUP** – stay together - Hamstring sweeps x20m - Lunges (pelvic push) + rotate + stand and glut hold (40m total) - Dynamic stretches leg swings (f/b & s/s) Calf pumps - Grapevines x20m each way - Stride outs (60-80-100%)	• This is to be consistent throughout each session • Warm-up is **coach led with athlete input** • Technical advice is given to correct any technical errors but questioning included
Body of session (25mins)	To cover key aspects associated with knee drive	**1) Skipping (moderate intensity) 3x20m total** *(All together – feminine side – kickboxers knee)* - Skipping with good posture, getting <u>knee up to 90</u> - Same again but this time get the <u>arms working</u> as well - Skip for height this time – <u>big knee drive</u> (control posture and coordinate arms) **2) 2 foot skip to single knee drive (with hop between) 20m** – rhythm and coordination *(year 10s nailed the drills last week, can you get one up on them)* - Trying to coordinate unilateral and bilateral movements together <u>Focus being knee to 90, arms and posture</u> **3) High knees** (partner hands are target) - Partner holds hands in front at hip height, you have to hit these with knees - switch **4) Stride outs x2** (*Show me what you have learnt)* - Stride out ensuring knee drive and aggressive arms Will probably all do weird slow high knee running – discuss how it needs to be fast and aggressive. Demonstrate theirs and then proper. - Get them to repeat stride out	• Fun and inclusive • **Individual AND group drills** • **Problem solving included** • **Feedback told but athlete questioned** • Mix of internal and external cues • Drills to be demonstrated and told at same time. Get them to how before starting

		5) Ladders – Sideways, 2 feet in each square x 4 (2x each side) – start in snake formation? (nokia snake game, team is the snake) – stay close together, all one snake - High knees moving laterally for speed (must get knees up, stay up tall!!) **6) Ladders – Front on x 3** *(Person in front gets 3 square headstart, catch them – DQed if lose knees, posture or arms)* - One foot in each for speed!!! - Knees must be up and aggressive arms **7) Hurdle running (1 or 2 feet apart) x2 – group punishment if hurdles get hit (burpees)** - One foot between each hurdle, getting knees up high (posture and arms) - 2nd time is for speed **8) Hurdle running at increasing distances (actually running this time) x2** - One foot between each hurdle, getting knees up high, must move horizontally this time (posture and arms) DO NOT BECOME BOOTYLICIOUS **9) Stride out x3** - Keeping knees up high but driving aggressively. Spend some time here giving individual feedback on form (posture, arms or knees)	Celebrate success by high fives with team. Also pull in for group huddles – emphasises group environment more
Cool down and recap of key points (5mins)		Release muscle tension and recap on session	• Coach and athlete led, get them to take charge and demonstrate

<u>Session 4 = High knees</u>

Traditional session plan – Coach 2

(50mins) Session focus = To be more effective with ground contact

Session component	Key outcomes	Activities / drills	Teaching points
Warm up and intro (15mins)	To prepare subjects for exercise, both physically and mentally	- **Recap on cues from week before – want to see them in all drills today** - Run gym length x8 **– Individual** - Hamstring sweeps x20m - Lunges (pelvic push) + rotate + stand and glut hold (40m total) - Dynamic stretches leg swings (f/b & s/s) Calf pumps - Grapevines x20m each way - Stride outs (60-80-100%)	• This is to be consistent throughout each session • Warm-up is always **coach led** • Technical advice **is given** to correct any technical errors
Body of session (25mins)	To cover key aspects associated with knee drive	**1) Balls of your feet drill – stiff legs** - Two foot jumping (small) on balls of feet only (x20) – **Like sneaking out of the house!!!** - Repeat and introduce <u>quiet landings (x20)</u> (must stay on balls of feet, and cushion each landing) – **Ninjas!!!!** - Repeat and introduce quickness off ground <u>(dorsiflexion - toes to knees)</u> – keeping toes up to prepare for landing – **Springy!!** <u>We want all of these to be present at the same time – balls of feet, quiet and fast!</u> **2) Balls of feet drill (2-1)** - Begin on two feet, then alternate one leg drive to chest. - You be the caller – they bounce on two feet (balls), you say left or right and they do a super fast knee drive to chest on that leg (maintain posture and hips). - Then include stride out in to it. (i.e. left, left, right, stride) where they run to half way <u>Change it up by swapping left and right over – or using different words for each movement</u> **3) High knees (15 contacts) – We have done it a lot – show us what you have learned.** - Want to see fast feet, balls of feet, quiet, knees to 90, Big Dawg posture - DO EACH ONE BY ONE and give one point to work on then repeat	• Fun and inclusive • **Individual drills and feedback** • **Feedback TOLD and athlete not questioned** • Mix of internal and external cues • Drills to be demonstrated and told at same time. Get them to how before starting

		4) Walking drill, clawing the ground – like riding a scooter! - Walking alternating legs, and clawing the ground as the foot touches down (knee to 90 degrees then pulling through the ground underneath body– not just putting it down). – fast and aggressive foot placement **5) Small cone accelerations** - Place cones at increasing distances for them to run over – (perhaps do more than one row) - They are to run over them but focus on clawing the ground and accelerating faster each step!!! - Focus – clawing, balls of feet, posture, arms **6) Stride outs** - Focus on clawing the ground, balls of feet, AND GETTING FOOT DOWN QUICKER - Remember for fast feet we need to have fast arms Give some feedback or rating for each	Celebrate success with high fives with coach. Give feedback one on one to promote more individual environment
Cool down and recap of key points (5mins)		Release muscle tension and recap on session Hand out forms!!!	• **Coach led**

Progressive session plan – Coach 1
(50mins) Session focus = To be more effective with ground contact

<table>
<tr><th>Session component</th><th>Key outcomes</th><th>Activities / drills</th><th>Teaching points</th></tr>
<tr><td>Warm up (15mins)</td><td>To prepare subjects for exercise, both physically and mentally</td><td>- Question on cues from last week – want to see this in all drills
- Run gym length x8 – GROUP – stay together
- Hamstring sweeps x20m
- Lunges (pelvic push)
+ rotate
+ stand and glut hold
(40m total)
- Dynamic stretches
leg swings (f/b & s/s)
Calf pumps
- Grapevines x20m each way
- Stride outs (60-80-100%)</td><td>• This is to be consistent throughout each session
• Warm-up is coach led with athlete input
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<tr><td>Body of session (25mins)</td><td>To cover key aspects associated with knee drive</td><td>1) Balls of your feet drill – stiff legs
- Two foot jumping (small) on balls of feet only (x20) – Like sneaking out of the house!!!
- Repeat and introduce <u>quiet landings (x20)</u> (must stay on balls of feet, and cushion each landing) – Ninjas!!!!
- Repeat and introduce quickness off ground <u>(dorsiflexion - toes to knees)</u> – keeping toes up to prepare for landing – Springy!!

Master tag – two feet only – balls of feet

<u>We want all of these to be present at the same time – balls of feet, quiet and fast!</u>

2) Balls of feet drill (2-1)
- Begin on two feet, then alternate one leg drive to chest.
- They are the caller – they bounce on two feet (balls), you say left or right and they do a super fast knee drive to chest on that leg (maintain posture and hips).
- Then include stride out in to it. (i.e. left, left, right, stride) where they run to half way
<u>Change it up by swapping left and right over – or using different words for each movement</u>

3) High knees (15 contacts) – We have done it a lot – show us what you have learned.</td><td>• Fun and inclusive
• Individual AND group drills
• Problem solving included
• Feedback told but athlete questioned
• Mix of internal and external cues
• Drills to be demonstrated and told at same time. Get them to how before starting</td></tr>
</table>

		- Want to see fast feet, balls of feet, quiet, knees to 90, Big Dawg posture - As a team – I call the rhythm **4) Walking drill, clawing the ground – like riding a scooter!** - Walking alternating legs, and clawing the ground as the foot touches down (knee to 90 degrees then pulling through the ground underneath body– not just putting it down). – fast and aggressive foot placement **5) Small cone accelerations** - Place cones at increasing distances for them to run over – (perhaps do more than one row) - They are to run over them but focus on clawing the ground and accelerating faster each step!!! - Focus – clawing, balls of feet, posture, arms **6) Stride outs** - Focus on clawing the ground, balls of feet, AND GETTING FOOT DOWN QUICKER - Remember for fast feet we need to have fast arms Give some feedback or rating for each	Celebrate success by high fives with team. Also pull in for group huddles – emphasises group environment more
Cool down and recap of key points (5mins)		Release muscle tension and recap on session Hand out forms!!!	• Coach and athlete led, get them to take charge and demonstrate

Session 5 = All together

Traditional session plan – Coach 2

(45mins) Session focus = Putting it all together

Session component	Key outcomes	Activities / drills	Teaching points
Warm up and intro (15mins)	To prepare subjects for exercise, both physically and mentally	- **Recap on cues from week before – want to see them in all drills today** - Run gym length x8 **– Individual** - Hamstring sweeps x20m - Lunges (pelvic push) + rotate + stand and glut hold (40m total) - Dynamic stretches leg swings (f/b & s/s) Calf pumps - Grapevines x20m each way - Stride outs (60-80-100%)	• This is to be consistent throughout each session • Warm-up is always **coach led** • Technical advice **is given** to correct any technical errors
Body of session (20mins)	To put each of the key teaching points into practise and receive feedback about their performance	Staff with ipads filming each of the students and GIVING feedback to them Key cues around posture, arms, knee drive and ground contact 20mins total Finish with survey	• Fun and inclusive • **Individual drills and feedback** • **Feedback TOLD and athlete not questioned** • Mix of internal and external cues • Drills to be demonstrated and told at same time. Get them to how before starting Celebrate success with high fives with coach. Give feedback one on one to promote more individual environment
Survey (10mins)	Feedback from students	Describe importance of survey	• **Coach led**

Progressive session plan – Coach 1
(45mins) Session focus = Putting it all together

Session component	Key outcomes	Activities / drills	Teaching points
Warm up (15mins)	To prepare subjects for exercise, both physically and mentally	- **Question on cues from last week – want to see this in all drills** - Run gym length x8 **– GROUP** – stay together - Hamstring sweeps x20m - Lunges (pelvic push) + rotate + stand and glut hold (40m total) - Dynamic stretches leg swings (f/b & s/s) Calf pumps - Grapevines x20m each way - Stride outs (60-80-100%)	• This is to be consistent throughout each session • Warm-up is **coach led with athlete input** • Technical advice is given to correct any technical errors but questioning included
Body of session (20mins)	To cover key aspects associated with knee drive	Students with ipads filming each of their partners and giving feedback to them Key cues around posture, arms, knee drive and ground contact 20mins total Finish with survey	• Fun and inclusive • **Individual AND group drills** • **Problem solving included** • **Feedback told but athlete questioned** • Mix of internal and external cues • Drills to be demonstrated and told at same time. Get them to how before starting Celebrate success by high fives with team. Also pull in for group huddles – emphasises group environment more
Survey (10mins)	Feedback from students	Describe importance of survey	• **Coach led**

Appendix 3: Pre and post mean ± SD kinematic measures for training and maturation groups

		Control						Traditional						Progressive					
		Pre	±	SD	Post	±	SD	Pre	±	SD	Post	±	SD	Pre	±	SD	Post	±	SD
SL S1 (m)	**All**	1.04	±	0.09	1.08	±	0.14	1.08	±	0.11	1.12	±	0.14‡	1.06	±	0.11	1.07	±	0.11
	Pre	1.00	±	0.05	1.03	±	0.08							0.98	±	0.06	1.02	±	0.07
	Circa	1.04	±	0.10	1.04	±	0.17	1.11	±	0.05	1.20	±	0.20	0.96	±	0.11	0.99	±	0.12
	Post	1.07	±	0.07	1.15	±	0.08	1.09	±	0.10	1.12	±	0.08*	1.11	±	0.10	1.11	±	0.09
SL S2 (m)	**All**	1.15	±	0.19	1.20	±	0.11*	1.22	±	0.11	1.21	±	0.13	1.17	±	0.12	1.20	±	0.13
	Pre	1.14	±	0.09	1.14	±	0.07		±			±		1.07	±	0.08	1.12	±	0.15
	Circa	1.14	±	0.12	1.19	±	0.10*	1.21	±	0.12	1.17	±	0.10†	1.13	±	0.08	1.17	±	0.11
	Post	1.17	±	0.11	1.25	±	0.13*	1.24	±	0.10	1.24	±	0.12†	1.22	±	0.13	1.23	±	0.12†
SL S3 (m)	**All**	1.27	±	0.09	1.23	±	0.10	1.32	±	0.14	1.31	±	0.11	1.29	±	0.13	1.32	±	0.17
	Pre	1.27	±	0.05	1.24	±	0.05							1.22	±	0.11	1.29	±	0.09
	Circa	1.26	±	0.10	1.27	±	0.09	1.34	±	0.11	1.29	±	0.11	1.25	±	0.09	1.30	±	0.16
	Post	1.30	±	0.09	1.37	±	0.10*	1.34	±	0.13	1.34	±	0.10†	1.33	±	0.13	1.33	±	0.11†
SL S4 (m)	**All**	1.35	±	0.10	1.35	±	0.08	1.36	±	0.11	1.34	±	0.14	1.38	±	0.16	1.39	±	0.17
	Pre	1.30	±	0.10	1.27	±	0.06							1.25	±	0.10	1.35	±	0.09
	Circa	1.32	±	0.09	1.34	±	0.08							1.30	±	0.05	1.31	±	0.07
	Post	1.43	±	0.07	1.42	±	0.05	1.39	±	0.09	1.37	±	0.12	1.44	±	0.17	1.43	±	0.14
SL 15m (m)	**All**	1.71	±	0.10	1.73	±	0.11	1.76	±	0.12	1.76	±	0.12	1.70	±	0.14	1.75	±	0.12*
	Pre	1.68	±	0.09	1.69	±	0.12							1.67	±	0.05	1.67	±	0.06
	Circa	1.67	±	0.08	1.70	±	0.08	1.75	±	0.08	1.76	±	0.12	1.68	±	0.03	1.77	±	0.03*
	Post	1.78	±	0.10	1.78	±	0.14	1.78	±	0.12	1.78	±	0.10	1.72	±	0.18	1.76	±	0.14
CT S1 (s)	**All**	0.22	±	0.02	0.22	±	0.03*	0.25	±	0.19	0.22	±	0.03	0.22	±	0.03	0.22	±	0.02
	Pre	0.21	±	0.04	0.21	±	0.04	0.22	±	0.01	0.22	±	0.03	0.22	±	0.04	0.22	±	0.03
	Circa	0.22	±	0.03	0.22	±	0.03	0.21	±	0.03	0.22	±	0.03	0.21	±	0.02	0.21	±	0.02
	Post	0.22	±	0.01	0.23	±	0.02*	0.28	±	0.24	0.22	±	0.03	0.23	±	0.03	0.23	±	0.02†
CT S2 (s)	**All**	0.22	±	0.10	0.20	±	0.02	0.20	±	0.02	0.20	±	0.02	0.20	±	0.02	0.20	±	0.02
	Pre	0.20	±	0.02	0.21	±	0.03	0.20	±	0.02	0.20	±	0.01	0.20	±	0.02	0.19	±	0.02
	Circa	0.24	±	0.13	0.20	±	0.02	0.20	±	0.03	0.19	±	0.01*‡	0.19	±	0.02	0.19	±	0.02
	Post	0.20	±	0.02	0.19	±	0.01	0.19	±	0.01	0.20	±	0.02	0.20	±	0.02	0.21	±	0.02
CT S3 (s)	**All**	0.19	±	0.02	0.19	±	0.02	0.18	±	0.02	0.18	±	0.02	0.19	±	0.02	0.18	±	0.02
	Pre	0.18	±	0.02	0.18	±	0.03	0.19	±	0.02	0.19	±	0.01	0.19	±	0.03	0.18	±	0.02
	Circa	0.19	±	0.02	0.19	±	0.02	0.18	±	0.02	0.18	±	0.01	0.18	±	0.02	0.18	±	0.01

	Post	0.19 ± 0.01	0.19 ± 0.01	0.18 ± 0.01	0.18 ± 0.02	0.19 ± 0.02	0.19 ± 0.02
CT S4 (s)	**All**	0.17 ± 0.02	0.17 ± 0.02	0.17 ± 0.02	0.17 ± 0.01	0.18 ± 0.02	0.17 ± 0.02
	Pre	0.16 ± 0.03	0.17 ± 0.02	0.17 ± 0.02	0.17 ± 0.01	0.18 ± 0.03	0.16 ± 0.01
	Circa	0.18 ± 0.02	0.17 ± 0.02	0.18 ± 0.02	0.16 ± 0.02*	0.17 ± 0.02	0.17 ± 0.02
	Post	0.17 ± 0.02	0.17 ± 0.01	0.17 ± 0.02	0.17 ± 0.01	0.18 ± 0.02	0.18 ± 0.02
CT 15m (s)	**All**	0.18 ± 0.10	0.15 ± 0.02	0.16 ± 0.02	0.15 ± 0.01*‡	0.16 ± 0.02	0.15 ± 0.02
	Pre	0.15 ± 0.02	0.15 ± 0.02	0.17 ± 0.02	0.15 ± 0.01	0.16 ± 0.03	0.15 ± 0.02
	Circa	0.20 ± 0.13	0.15 ± 0.02	0.16 ± 0.02	0.14 ± 0.02*‡	0.15 ± 0.02	0.15 ± 0.01
	Post	0.15 ± 0.01	0.15 ± 0.02	0.15 ± 0.02	0.15 ± 0.01	0.16 ± 0.02	0.16 ± 0.02
FT S1 (s)	**All**	0.05 ± 0.02	0.05 ± 0.01	0.05 ± 0.02	0.05 ± 0.02	0.05 ± 0.01	0.05 ± 0.01
	Pre	0.04 ± 0.02	0.05 ± 0.02	0.04 ± 0.01	0.04 ± 0.02	0.05 ± 0.01	0.05 ± 0.01
	Circa	0.05 ± 0.01	0.05 ± 0.01	0.05 ± 0.02	0.06 ± 0.02*†	0.05 ± 0.01	0.05 ± 0.02
	Post	0.05 ± 0.02	0.05 ± 0.01	0.05 ± 0.02	0.05 ± 0.01	0.04 ± 0.02	0.04 ± 0.01
FT S2 (s)	**All**	0.06 ± 0.02	0.06 ± 0.01	0.06 ± 0.02	0.06 ± 0.02	0.06 ± 0.01	0.06 ± 0.02
	Pre	0.06 ± 0.00	0.05 ± 0.01	0.05 ± 0.01	0.05 ± 0.02	0.05 ± 0.00	0.06 ± 0.01
	Circa	0.06 ± 0.02	0.06 ± 0.02	0.06 ± 0.01	0.06 ± 0.02	0.05 ± 0.01	0.05 ± 0.02
	Post	0.06 ± 0.01	0.06 ± 0.01	0.06 ± 0.02	0.06 ± 0.02	0.06 ± 0.02	0.06 ± 0.02
FT S3 (s)	**All**	0.07 ± 0.01	0.07 ± 0.01	0.07 ± 0.02	0.08 ± 0.08	0.07 ± 0.01	0.07 ± 0.01
	Pre	0.07 ± 0.01	0.07 ± 0.01	0.07 ± 0.01	0.15 ± 0.22	0.07 ± 0.01	0.08 ± 0.02
	Circa	0.07 ± 0.01	0.07 ± 0.01	0.07 ± 0.01	0.07 ± 0.02	0.07 ± 0.01	0.07 ± 0.01
	Post	0.07 ± 0.02	0.07 ± 0.01*	0.07 ± 0.02	0.07 ± 0.01	0.07 ± 0.02	0.07 ± 0.01
FT 15m (s)	**All**	0.09 ± 0.01	0.10 ± 0.01	0.09 ± 0.02	0.10 ± 0.02*	0.09 ± 0.02	0.10 ± 0.01*
	Pre	0.10 ± 0.02	0.11 ± 0.01	0.09 ± 0.01	0.10 ± 0.02	0.10 ± 0.02	0.10 ± 0.01
	Circa	0.09 ± 0.01	0.09 ± 0.01	0.09 ± 0.02	0.10 ± 0.01*	0.09 ± 0.02	0.10 ± 0.01*†
	Post	0.09 ± 0.01	0.10 ± 0.02	0.10 ± 0.01	0.10 ± 0.02	0.09 ± 0.02	0.10 ± 0.01
SF S1 (Hz)	**All**	3.82 ± 0.40	3.73 ± 0.37	3.74 ± 0.51	3.82 ± 0.44†	3.86 ± 0.45	3.80 ± 0.32
	Pre	3.94 ± 0.47	3.91 ± 0.35	3.92 ± 0.36	3.90 ± 0.71	3.84 ± 0.56	3.73 ± 0.32
	Circa	3.81 ± 0.44	3.77 ± 0.35	3.90 ± 0.45	3.70 ± 0.40	4.03 ± 0.40	3.92 ± 0.38
	Post	3.80 ± 0.34	3.57 ± 0.38	3.63 ± 0.55	3.85 ± 0.40†	3.77 ± 0.45	3.75 ± 0.28
SF S2 (Hz)	**All**	3.80 ± 0.48	3.92 ± 0.34	3.90 ± 0.31	3.88 ± 0.46	3.96 ± 0.34	3.90 ± 0.33
	Pre	3.91 ± 0.34	3.91 ± 0.29	4.00 ± 0.17	3.60 ± 0.93	3.99 ± 0.36	4.06 ± 0.35
	Circa	3.68 ± 0.57	3.88 ± 0.37	3.80 ± 0.34	4.01 ± 0.36‡	4.18 ± 0.35	4.02 ± 0.33†
	Post	3.98 ± 0.25	4.00 ± 0.35	3.91 ± 0.32	3.89 ± 0.34	3.84 ± 0.28	3.80 ± 0.32
SF S3 (Hz)	**All**	3.91 ± 0.26	3.98 ± 0.40	3.96 ± 0.35	3.98 ± 0.32	3.99 ± 0.33	3.99 ± 0.37

	Pre	4.10 ± 0.08	4.36 ± 0.85	3.96 ± 0.55	3.91 ± 0.45	3.92 ± 0.41	3.89 ± 0.58
	Circa	3.89 ± 0.25	3.93 ± 0.34	3.94 ± 0.35	3.92 ± 0.27	4.10 ± 0.31	4.10 ± 0.38
	Post	3.89 ± 0.31	3.91 ± 0.22	3.97 ± 0.33	4.01 ± 0.32	3.96 ± 0.33	3.97 ± 0.32
Sf 15m (Hz)	**All**	3.93 ± 0.43	4.05 ± 0.33	4.05 ± 0.36	4.10 ± 0.38	4.10 ± 0.40	4.24 ± 0.90
	Pre	3.96 ± 0.23	4.01 ± 0.30	3.85 ± 0.32	4.01 ± 0.32	3.90 ± 0.44	4.06 ± 0.16
	Circa	3.84 ± 0.52	4.06 ± 0.31	4.13 ± 0.43	4.13 ± 0.38	4.18 ± 0.48	4.01 ± 0.30†
	Post	4.08 ± 0.26	4.04 ± 0.43	4.06 ± 0.34	4.11 ± 0.42	4.10 ± 0.33	4.43 ± 1.19

Note: * = significant difference (*p*<0.05) pre vs post; † = significant difference (*p*<0.05) to control change scores, ‡ = significant difference (*p*<0.05) to traditional change scores.