The Benefits of Resistance Training with and Without Weightlifting for Athletic Performance in Adolescent Males

Andrew Warren Pichardo

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

2019

Primary Supervisor: Dr Craig Harrison

Co-Supervisor: Dr Jon Oliver

Co-Supervisor: Dr Peter Maulder

Sports Performance Research Institute New Zealand

Auckland University of Technology, Auckland, New Zealand

Abstract

Children and adolescents should engage in a variety of activities to develop muscular strength and motor skill performance in tasks such as running, jumping, and throwing. Resistance training and weightlifting are safe and effective methods to improve the athleticism of youth males. The overarching research question of this thesis was "is resistance training more beneficial with or without weightlifting for adolescent athletes?" Chapter 1 serves to provide background information, a rationale for the research, the purpose and significance of the thesis, and the thesis structure. Chapter 2 is a narrative review of existing models of youth development. These existing models highlight the trainability of all fitness components in youth through common resistance training methods, such as traditional strength training, plyometrics, and weightlifting. Chapter 3 provides an applied example of how practitioners can effectively implement these resistance training methods within secondary school curriculum. Specifically, recommendations regarding periodization and delivering the program are given to assist physical education teachers and coaches working with youth athletes. Chapter 4 examined the influence of maturity offset, strength, and movement competency on sprinting, jumping, and upper body power. Notably, relative strength was significantly correlated to all motor skill tasks (r = 0.28-0.61), reinforcing the idea that practitioners should prioritize strength when working with adolescents. Chapter 5 investigated how motor skills develop after an academic year of combined resistance training (CRT) or combined resistance training with weightlifting (CRT&WL) (28 total training weeks). There were no differences between improvements in various motor skills when comparing both groups. The time course of adaptation was similar between groups but was variable dependent. Movement competency and strength improved more during the first half of the training program, while sprint, jump, and throw performance improved more in the second half of the training program. This suggests youth need higher training intensities to stimulate expression of their recently developed strength into other motor skills. Chapter 6 examined how the CRT and CRT&WL training programs affect lower-extremity injury risk factors and resistance training skill. The CRT made significant improvements in tuck jump performance, whereas both training groups made significant improvements in resistance training skill after the year. Chapter 7 includes an overall summary, which suggests that both CRT and CRT&WL are effective for improving the athleticism of adolescent males.

Table of Contents

List of Figures

List of Tables

Attestation of Authorship

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

…………………………....

Andrew Warren Pichardo

Co-Authored Works

Pichardo A.W., Oliver J.L., Harrison C.B., Maulder P.S., & Lloyd RS (2018). Integrating models of long-term athletic development to maximize the physical development of youth. *International Journal of Sports Science & Coaching*, 13(6), 1189-1199.

(Pichardo 85%, Oliver 5%, Harrison 2.5%, Maulder 2.5%, Lloyd 5%)

Pichardo A.W., Oliver J.L., Harrison C.B., Maulder P.S., & Lloyd R.S. (2019). Integrating resistance training into high school curriculum. *Strength and Conditioning Journal*, 41(1), 39-50.

(Pichardo 85%, Oliver 5%, Harrison 2.5%, Maulder 2.5%, Lloyd 5%)

Pichardo A.W., Oliver J.L., Harrison C.B., Maulder P.S., Lloyd R.S., & Kandoi R. (2019). The influence of maturity offset, strength, and movement competency on motor skill performance in adolescent males. *Sports*. 7(168), 1-11.

(Pichardo 80%, Oliver 5%, Harrison 2.5%, Maulder 2.5%, Lloyd 5%, Kandoi 5%)

Pichardo A.W., Oliver J.L., Harrison C.B., Maulder P.S., Lloyd R.S., & Kandoi R. (2019). Effects of combined resistance training and weightlifting on motor skill performance of adolescent male athletes. *Journal of Strength and Conditioning Research*, Published ahead of print.

(Pichardo 80%, Oliver 5%, Harrison 2.5%, Maulder 2.5%, Lloyd 5%, Kandoi 5%)

Pichardo A.W., Oliver J.L., Harrison C.B., Maulder P.S., Lloyd R.S., & Kandoi R. (2019). Effects of combined resistance training and weightlifting on injury risk factors and resistance training skill of adolescent males. *Journal of Strength and Conditioning Research*, Post acceptance.

(Pichardo 80%, Oliver 5%, Harrison 2.5%, Maulder 2.5%, Lloyd 5%, Kandoi 5%)

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

<u>Supervisors</u>

Dr Craig B Harrison	Dr Jon L Oliver	Dr Peter S Maulder
Primary	Secondary	Tertiary

<u>Collaborators:</u>

Dr Rhodri S Lloyd	Rohan Kandoi

Acknowledgements

First and foremost, I would like to thank my family for their continued support throughout this whole journey. The Skype calls, packages, and y'alls visit helped kept me sane when it was needed most. Mom and Dad, thank you for all the ways you helped me develop as a person who was willing to take on such a challenge and never give up, as well as making it a reality for me to pursue my dreams. And to Al, you've always been my biggest supporter and I'm so thankful to have that in a brother. I also thank you for your musical influences, which oddly but undoubtedly helped me undertake and complete this journey. Although I've thoroughly enjoyed New Zealand, I will also enjoy spending more time with y'all upon my return stateside.

I am also immensely appreciative of all the academic staff at AUT and Wintec that have contributed to shaping me as a professional. Thank you, JC, for providing me this opportunity and for always inspiring us young professionals to be better. The writing retreats, workshops, sport sessions, and pub chats have been hugely valuable in intangible ways. Thank you, JLO, for your massive contributions to my development as a researcher and practitioner. Your insight and expertise has deepened my knowledge about the whole research process, which is invaluable for my career. Pete, huge thanks to you and your team for all the help in the trenches of data collection. I am so grateful for the opportunities you and Wintec have provided me over the years and look forward to our collaboration in the future. To Craig, thanks for the good chats and your general guidance along the way. Your unique perspectives have ultimately provided immense growth for me, which I am forever grateful for. A huge thank you to everyone else at AUT. The staff and postgraduate students are so welcoming to international students and although being a distance student has its drawbacks at times, I am still so glad I decided to embark on this journey in New Zealand.

To everyone at St John's College, thank you for your help, patience, and understanding over the past three years. The entire staff was so helpful in many small but crucial ways, such as providing batteries for scales, cameras for filming, and gym space for testing. To the physical education staff, thank you all for help with data collection, learning the school systems, and accommodating for my data collection and intervention delivery. To all the students, thank

you for your participation and maximum effort, I hope you all enjoyed the process as much as I did.

And finally, thank you Lesley for joining me on this overseas journey and either being the calm in my storm or putting the wind in my sails when it was needed. You've listened to hours of presentations, as well as a few rants, and I've always valued your level-headed approach to things. I thank you also for your patience with and support for me throughout this journey, which has been invaluable. It is exciting watching you grow and learn and experience the journey yourself and am looking forward to what the future holds for us.

Ethics Approval

Ethical approval for the thesis research was granted by the Auckland University of Technology Ethics Committee (AUTEC) on 29th March 2016 for a period of three years:

- 17/11 The benefits of resistance training with or without weightlifting for youth athlete development

Chapter 1: Introduction

Rationale

Proper application of pediatric training principles can have a lasting impact on long-term athletic development (LTAD). Several theoretical models have been proposed to structure pathways for optimal athletic development, which may vary based on a child’s long-term goal [1-3]. Additionally, stages from these models have been adopted in subsequent models focused specifically on resistance training methods [4-6] and various fitness components [4, 7-10]. However, due to the volume and variety of information, it may be difficult for practitioners to synthesize the underlying themes across a variety of models regarding youth physical development. Therefore, further integration is needed to help practitioners understand how these models align to each other and ultimately, how to best physically develop youth.

Middle and secondary school provide a good opportunity to expose youth to more structured resistance training. Long interventions (> 23 weeks) utilizing a high training intensity (80-89% of one repetition maximum [1RM]) are most effective in improving muscular strength in children and adolescents [11]. Resistance or neuromuscular training programs implemented through a club or team may not meet the recommended length or intensity needed to stimulate strength gains, due to a shorter season length or lack of resources for grassroots level athletes. The inherent nature of school encourages high compliance rates and long-term training programs, as well as access to a school’s strength and conditioning facilities, which often exceed the quality of grassroots sports leagues. However, there is little literature providing guidance to coaches about how to effectively implement resistance training into school curriculum. In fact, most high school physical education teachers and sport coaches do not have the required knowledge to design, implement, and supervise resistance training programs [12]. Jeffreys [13] presented a multi-year plan for training the high school athlete but there was little detail about each stage of training, so inexperienced practitioners may struggle to design and implement programs based on his suggestions alone. Therefore, further detailed guidelines are needed to educate coaches and teachers about the design and implementation of resistance training programs into secondary school curriculum.

Resistance training is a relatively safe and effective method to improve performance and reduce the risk of injury in young athletes [14]. Meta-analyses indicate that resistance training is effective in improving muscular strength [15] and motor skill performance of tasks such as jumping, running, and throwing [16]. Several studies suggest a combination of traditional strength training and plyometrics are more effective in improving jump and sprint performance in young males than one exclusively [17, 18]. Weightlifting training has also been shown to improve vertical and horizontal jump (HJ) and sprint performance after 12 weeks in prepubertal athletes [19], as well as vertical jump performance after eight weeks in postpubertal athletes [20]. However, no research has compared the effects of CRT with or without weightlifting movements in a pubertal population, when children are going through a phase of rapid growth. Additionally, previous studies have commonly utilized a relatively short training program (8-12 weeks) [11] or do not measure motor skill performance over time [21]. Therefore, further investigation into the effects of a longer school-based resistance training program with or without weightlifting on motor skill performance is warranted.

Due to reduced neuromuscular control during the adolescent growth spurt, youth suffer more injuries during this period [22]. Several risk factors for lower extremity injury have been identified, which include movement skill, landing kinematics, and interlimb asymmetry [23]. Meta-analyses have shown that training programs that target strength, balance, agility, and landing can reduce the risk of lower extremity injury [24] and increase bone mineral content [25], which may help prevent traumatic sports injuries. However, no research has investigated the effects of school-based resistance training programs on injury risk factors in adolescent males. Specifically, no research has investigated the effects of weightlifting training on movement skill, landing kinematics, or interlimb asymmetry. Thus, the need for further research examining the effects of resistance training with or without weightlifting is evident.

Purpose

The overall purpose of this thesis was to examine the benefits of a curriculum-based resistance training program with and without weightlifting on athletic performance of youth males. Specifically, there were four objectives:

1. Review popular development models regarding the physical development of youth to help guide practitioners design resistance training programs.
2. Provide an applied example of an introductory resistance training program that can be implemented into secondary school curriculum.
3. Examine the influence of maturity offset, strength, and movement skill on motor skill performance.
4. Investigate the effects of resistance training with or without weightlifting on motor skill performance.
5. Investigate the effects of resistance training with or without weightlifting on lower-extremity injury risk factors.

Significance of thesis

Resistance training in youth is becoming more popular, particularly in middle and secondary school curriculum. Existing models of athletic development align physical training according to maturity status or stages from the Developmental Model of Sports Participation (DMSP) [1] and Balyi's LTAD model [2]. However, it may be difficult for practitioners to extract key themes from a variety of models. Therefore, this thesis will align previous athletic development models to each other to provide practitioners a more comprehensive view of the physical development of youth. Despite the growing popularity, most secondary school physical education teachers and sport coaches do not have the prerequisite knowledge to design and implement resistance training programs for youth [12]. Therefore, this thesis will provide an applied example to help guide practitioners in the implementation of these principles into an all boys' secondary school curriculum. Specifically, the periodization and progression of training variables, as well as insight regarding effective delivery of training content will assist high school practitioners to bridge the gap between scientific theory and practical application.

Existing studies utilizing weightlifting training interventions are limited to prepubertal [19] and postpubertal boys [20] or do not measure the effects on motor skill performance or injury risk factors [21, 26]. This thesis will add to the scant body of youth weightlifting literature by investigating a circa-PHV cohort over an academic year. Providing guidelines and empirical evidence from a high-school environment could have a substantial reach to practitioners working in schools, giving important information on how to design and implement CRT and CRT&WL programs in a school setting, as well as to understand the time course and magnitude of training adaptations.

Thesis structure

The thesis is comprised of seven chapters. All chapters except the first, fourth, and seventh were written in the format of the respective journal to which they were submitted. Chapters 2-6 begin with a preface that elucidates how each chapter is linked in the larger narrative. The five middle chapters are separated into two sections, as shown in Figure 1.1:

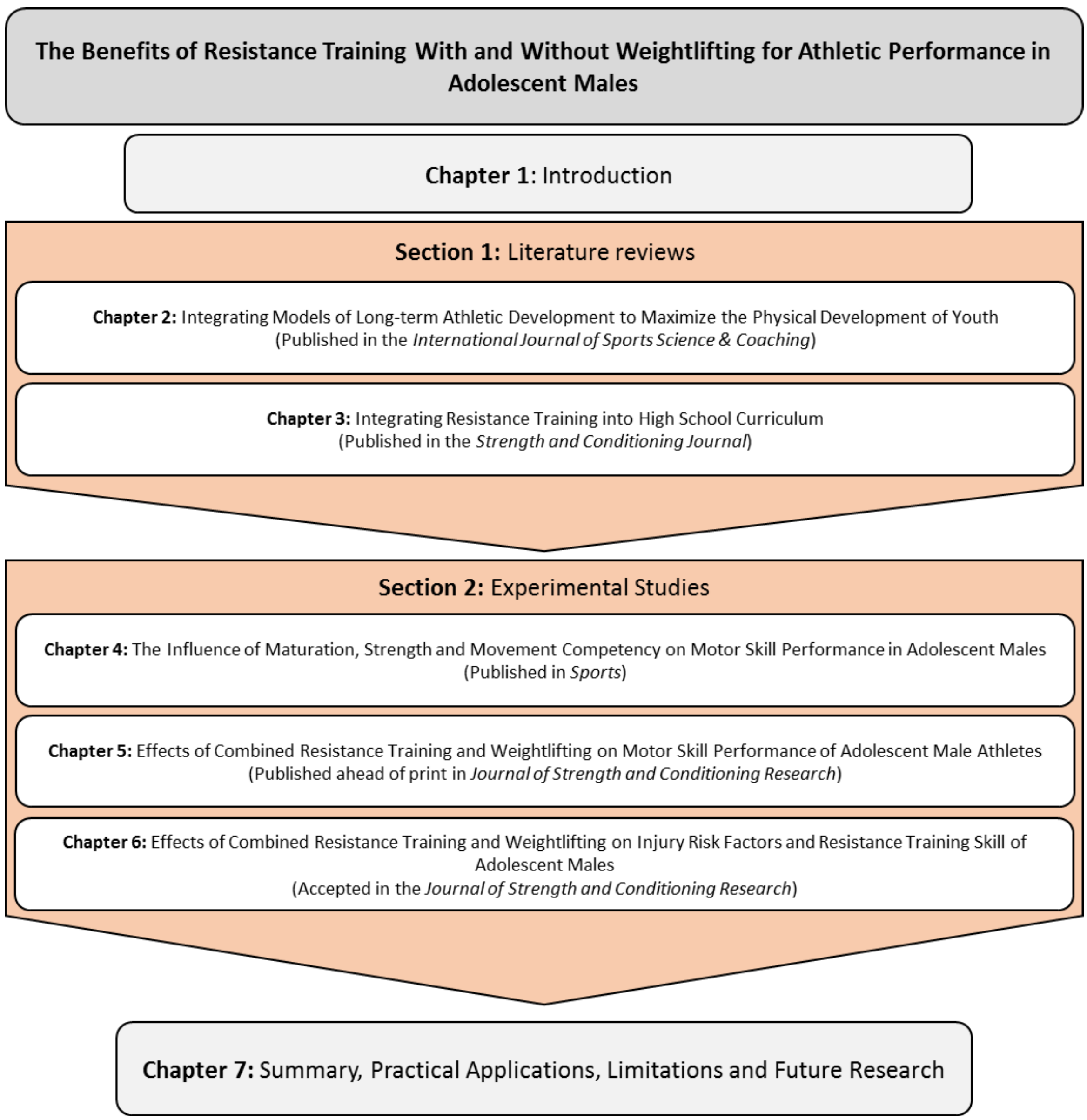

Figure 0.1. Thesis organization

The first section is comprised of two published narrative reviews. Chapter 2 examined existing models of athletic development, resistance training, and the development of specific fitness components. Chapter 3 provided an applied example of integrating resistance training into secondary school curriculum and pedagogical considerations for coaching youth. The second section consists of three experimental studies. Chapter 4 used a cross-sectional approach to examine the influence of maturation, strength, and athletic motor skill competencies on motor skill development of adolescent males. The intervention used for Chapters 5 and 6 were based of the guidelines presented in Chapter 3 and implemented using some of the strategies suggested. Chapter 5 investigated the effects of an academic year of CRT and CRT&WL on strength and motor skill performance. Chapter 6 examined how an academic year of CRT and CRT&WL affect injury risk factors and resistance training skill. Chapter 7 provides an overall summary, practical applications and limitations of the research presented, and directions for future research.

Chapter 2: Integrating Models of Long-term Athletic Development to Maximize the Physical Development of Youth

This chapter comprises the following article published in the *International Journal of Sports Science & Coaching.*

Reference:

Pichardo A.W., Oliver J.L., Harrison C.B., Maulder P.S., & Lloyd R.S. (2018). Integrating models of long-term athletic development to maximize the physical development of youth. *International Journal of Sports Science & Coaching,* 13(6), 1189-1199.

Introduction

In recent years, there has been a growing interest in LTAD models, with a need to properly prepare youth for both sport and a physically active life [14]. Over the last two decades, academics have proposed a number of LTAD models, with early general models structuring athletic development into stages based on participation, chronological age or maturation [1-3]. These general LTAD models provided frameworks for subsequent athletic development models specific to different types of physical training [4-6] and fitness, including aerobic fitness [10], muscular power [7], speed [8] and agility [9]. Identifying links between common themes of various models may provide coaches and practitioners valuable insight into components of a successful LTAD program. The purpose of this review is to examine existing models of LTAD regarding the physical preparation of youth.

General long-term athletic development models

Sport participation and athletic development models originated from basic models of talent development, such as the Differentiated Model of Giftedness and Talent [27]. The key concept that gifts are essentially innate, and youth can develop talent through practice remains integral in subsequent models of athletic development. Three models that have arguably had the largest influence on how youth athletes are physically developed are the DMSP by Côté [1], the LTAD model popularized by Balyi and Hamilton [2], and the Youth Physical Development (YPD) model proposed by Lloyd and Oliver [3]. While each of those models provide a unique perspective, they each provide a pathway for the development of athleticism based on either chronological age and/or maturation. According to the National Strength and Conditioning Association's (NSCA) position statement on LTAD [14], athleticism refers to the ability to repeatedly perform a range of movements which require competent levels of motor skills, strength, power, speed, agility, balance, coordination and endurance. Figure 2.1 provides an overview of how these three models align to each other. The figure shows that the foci in each model shifts with advancing age and maturity as youth progress towards adulthood.

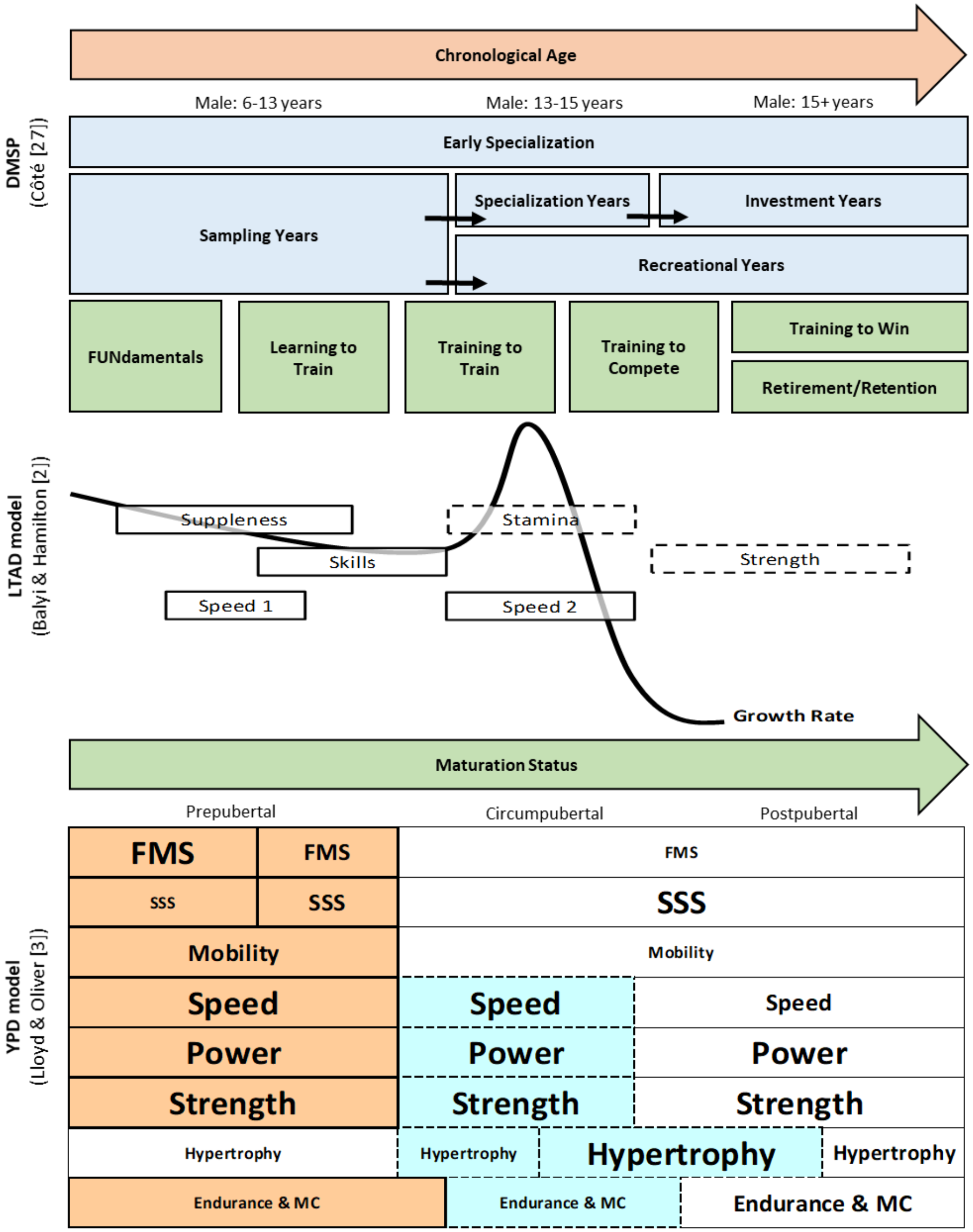

Figure 0.1. Composite diagram of three popular general models of long-term athletic development; the Developmental Model of Sports Participation (DMSP) (top, redrawn and adapted from Côté [1]), the Long-Term Athlete Development (LTAD) model (middle, redrawn and adapted from Balyi and Hamilton [2]), and the Youth Physical Development (YPD) model, bottom, redrawn and adapted from Lloyd and Oliver [3]). In the LTAD model, closed boxes align to chronological age and dashed boxes to maturation. In the YPD model, FMS = fundamental movement skills, SSS = sport-specific skills, MC = metabolic conditioning; font size represents the importance of a given fitness component at a given stage; shaded boxes identify interactions between training adaptations and maturation; bold box = prepuberty (predominantly neural adaptations), dashed box = pubertal (hormonal and neural adaptations).

The DMSP demonstrates the different pathways a child may take through their sporting career. Although titled a participation model, Côté [1] originally developed the DMSP following 15 individual interviews with four elite sporting families (three rowing, one tennis) and thus arguably better reflects a model of sporting excellence. Nonetheless, the DMSP identifies three developmental stages: the sampling years, the specializing years and the investment years. The sampling years (age 6-13) involve playing a variety of sports to provide fun and excitement though sport. After this stage, youth may choose to enter the specializing years (age 13-15) - a stage where sport involvement is limited to one or two roles and the role of deliberate practice is increased - or the recreational years (age 13+), in which they remain active for life through recreational sport. The investment years (age 15+) focus on achieving an elite level of performance in one activity. In this stage, the most important elements are strategic, competitive and skill development characteristics of sport.

Since its conception, subsequent athletic development models focused on physical fitness have aligned themselves with the DMSP's stages of participation [7, 10], as has a more recent version of the YPD model [28]. Furthermore, several position statements and studies support DMSP's sampling approach to help prevent burnout and overuse injuries in youth [14, 29-32]. Sampling different sports can develop a variety of fundamental movement skills (FMS), enhancing a young person's overall athleticism [14]. The DMSP describes participation and performance pathways based on chronological age. This means the proposed stages and their respective age ranges do not account for individual differences in timing and tempo of maturation, training age, and movement competency - all of which are important in the developing athlete [4, 14]. Training age refers to the number of years an athlete has been performing organized training and can vary based on context [3]. For example, an athlete who has been formally training for a sport for a number of years, but is new to resistance training, would have a training age of zero for resistance training. Nonetheless, the DMSP emphasizes the importance of sampling before specializing - a consistent theme throughout subsequent models describing the physical development of youth.

Following an examination of coaching knowledge and practice, McKeown and Ball [33] concluded that the most popular model of LTAD used by practitioners was the model proposed by Balyi and Hamilton [2] shown towards the middle of Figure 2.1. This model provides a framework whereby specific fitness components align to either chronological age or maturation. The authors recommended using peak height velocity (PHV), as opposed to chronological age, as a reference point for periods of enhanced trainability, or "windows of adaptation" [2]. Due to differing rates of maturation, PHV typically occurs around age 11.5 years and 13.5 years in North American females and males, respectively [34]. However, biological age only serves as the basis for the critical windows for strength and endurance (shown by boxes with dashed lines in Figure 2.1) with windows for speed, skill and suppleness based on chronological age (shown by boxes with solid line). According to this model, practitioners should emphasize aerobic development at the onset of PHV, while strength should be a focus approximately 12-18 months after PHV. Windows of opportunity are based on periods when fitness is naturally developing during growth and maturation, and the theory supposes that those periods represent a time when youth will be most responsive to training [35]. Balyi and colleagues [2, 36] further suggested that a failure to fully exploit a window of opportunity with adequate training would forever lower future adult potential. However, the existence of windows of opportunity has been questioned due to a lack of supporting empirical data [37]. Another feature of the Balyi and Hamilton [2] LTAD model is the use of stages to organize physical training progression. The FUNdamentals stage (age 6-9 males, 6-8 females) occurs during early childhood and refers to a period where children should learn fundamental movement skills in a fun environment. The emphasis during the Learning to Train stage (age 9-12 males, 8-11 females) is to learn fundamental sport-skills during a "window of adaptation" for motor coordination. Youth learning to move competently in fundamental and sport-specific skills serve as the basis for the FUNdamentals and Learning to Train stages. The Training to Train stage (age 12-16 males, 11-15 females) is a key time to develop physical fitness. The difference in age reflects the fact that girls mature earlier than boys and suggests maturation will interact with physical training. The Training to Compete (age 16-18 males, 15-17 females) and Training to Win (age 18+ males, 17+ females) stages are aimed at optimizing and maximizing fitness and sport performance. Lastly, the Retirement/Retention stage focuses on retaining ex-athletes in sport via coaching, officiating, administration or other avenues. The LTAD model undoubtedly offers a systematic approach to training and several of these stages have been subsequently featured in resistance training [4], plyometric [6] and weightlifting models [5].

Recent literature has questioned the suitability of the term "athlete" when delineating constructs surrounding the athletic development of youth [14]. Some argue that the term "athlete" in the LTAD model renders the structure as a means to solely developing athletes [28]. However, in light of the global numbers of obese, overweight, and physically illiterate children, LTAD should really be an initiative for all youth. Although originally presented as a participation model, the Balyi and Hamilton [2] model promotes high volumes of conditioning and training around adolescence, particularly through the 10,000 hour rule; however, the suitability of this approach has been questioned in the literature [37, 38]. The need to accumulate 10,000 hours of training (or deliberate practice) appears to be a misconception and may even be detrimental to long-term development [39]. The 10,000 hour rule for elite sporting attainment has been attributed to the work of Ericsson et al. [40]. But, in an editorial, Ericsson suggested that his work had been misrepresented and that the 10,000 hour rule was somewhat of a misnomer [41]. Ericsson [41] then claims that it is possible to reach an international level in much less time, consistent with findings from Baker and Young [42] that show elite level attainment in sport can occur with 4,000 to 6,000 hours of training which indicates that deliberate practice is more important than the quantity. Attempting to accumulate 10,000 hours of training might also increase the risk of overuse or acute injury or illness, especially during periods of rapid growth that are often synonymous with a loss of coordination [31, 39, 43, 44].

Since the inception of the Balyi and Hamilton [2] model, several subsequent development models [3, 4] and position statements regarding youth development [14] have discussed the importance of maturation on training adaptation. The YPD model (Lloyd and Oliver [3], bottom of Figure 2.1) was introduced to provide an evidence-based approach to training youth, describing how training and maturation may interact in the development of physical fitness. Additionally, the YPD model acknowledged the impact of training history, baseline fitness levels and sex differences on the decision-making process of training prescription. In contrast to the LTAD model, the YPD model includes nine physical qualities: FMS, sport-specific skill, mobility, agility, speed, power, strength, hypertrophy, and endurance and metabolic conditioning. An important construct of the YPD model is that research indicates that all physical qualities are trainable throughout childhood and adolescence, albeit that the magnitude and underlying adaptive mechanisms may differ according to maturation [3]. For example, a coach may place an emphasis on coordination and plyometrics in prepubertal children and hypertrophy and a combination of strength training and plyometrics in postpubertal youth [45].

The YPD model advocates that providing youth with opportunities to learn and challenge their coordinative abilities through the manipulation of task, individual and environmental constraints during a period of heightened central nervous system adaptability, should lead to improved motor skill development. In this regard, both the YPD and LTAD models are similar in that they prioritize the development of fundamental movement skills and movement competency from a young age. A subsequent Composite Youth Development model has been proposed [28], drawing from earlier talent [1] and physical [3] development models. The incorporation of DMSP stages offers a psychosocial emphasis throughout childhood and adolescence. This provides a holistic focus ensuring the child or adolescent maintains a healthy, physically active lifestyle [28].

Resistance training models for athletic development

Research demonstrates that participating in elite youth sport alone, without the addition of supplementary physical training, fails to optimize athletic development [46-48]. Resistance training refers to the specialized method of conditioning whereby an individual is working against resistive loads to enhance health, fitness and performance and includes the use of body weight, machines, free weights, bands and medicine balls [49, 50]. The most common forms of resistance training include bodyweight plyometric training, traditional strength training using external weight, or a combination of both of these. The use of resistance training as early as possible in a young athlete's development appears crucial [46-48]. Several position statements on LTAD [14], resistance training for youth [49-53], and injury prevention [29, 32] advocate the use of resistance training as an appropriate training method to improve sport performance and decrease risk of injury in youth. Furthermore, practitioners working with youth should understand the influence of growth and maturation on physiological adaptations and consider these factors when designing resistance training programs.

A meta-analysis by Behringer et al. [15] showed an interaction of maturity on strength gains following resistance training interventions; more mature children made greater gains in strength but immature children still made meaningful improvements. A later review by the same group [16] also showed that strength training transferred greater gains to running, jumping and throwing in immature children compared to mature children. Work by Behm et al. [54], as well as several experimental studies [46-48], show that resistance training is most specific to strength gains compared to other components of fitness. However, coaches often successfully utilize resistance training to improve power, speed, agility and even aerobic fitness performance of youth [11, 54].

The development of several resistance training models [4-6] align with the stages and concepts from earlier general LTAD models [1-3]. A combination of a resistance training [4], plyometric [6] and weightlifting [5] model is shown below in Figure 2.2. The figure demonstrates the overlap between several popular models to provide a more comprehensive description of when and how to implement various types of resistance training with youth.

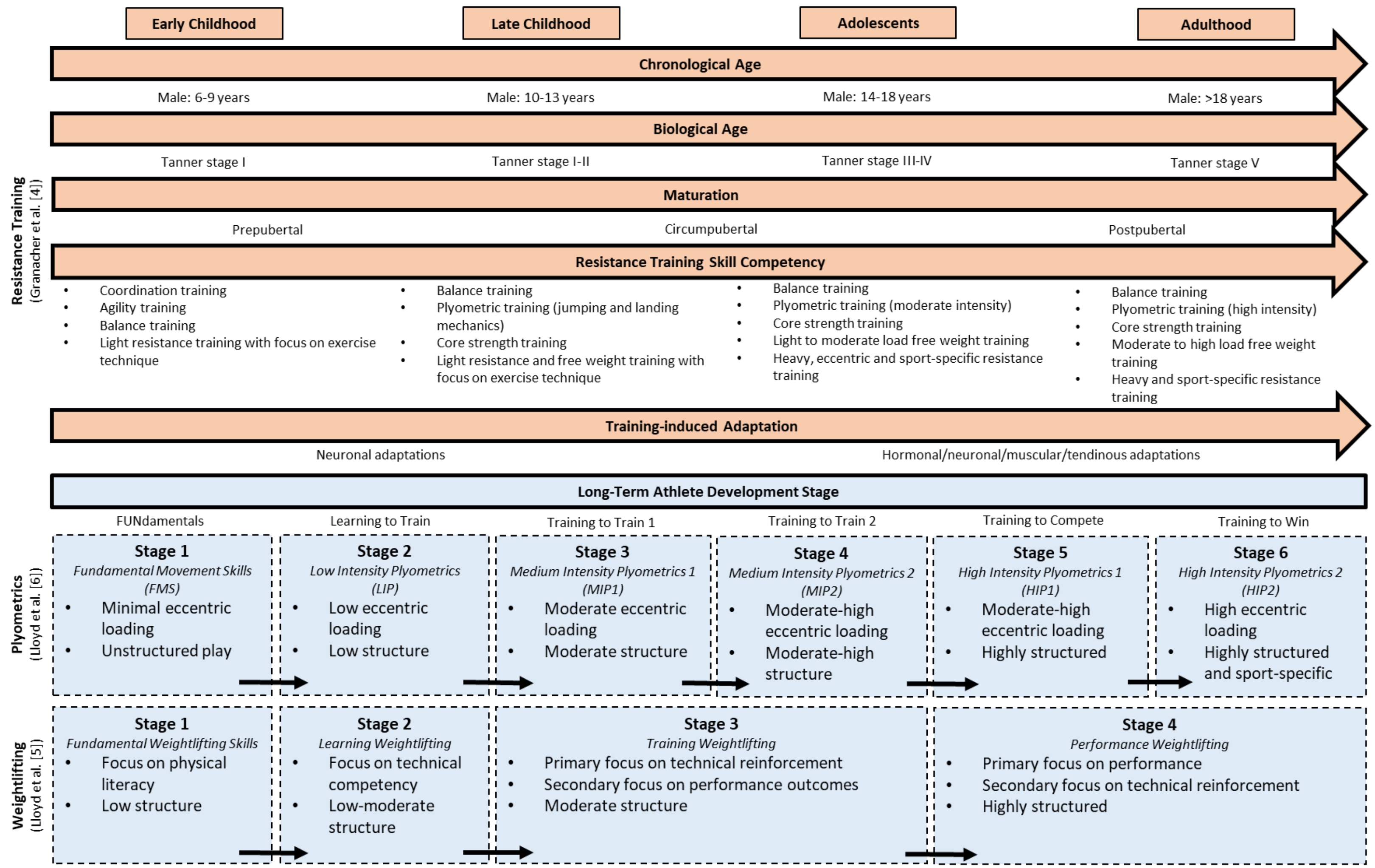

Figure 0.2. A summary of resistance training (top, redrawn and adapted from Granacher et al. [4]), plyometric (middle, adapted from Lloyd et al. [6]), and weightlifting (bottom, adapted from Lloyd et al. [5]) models. The dashed boxes at the bottom are aligned to different stages of the Balyi and Hamilton [2] model.

A conceptual model of resistance training, shown towards the top of Figure 2.2, was proposed within a systematic review on the effects of resistance training on muscular fitness (strength, power, endurance) [4]. The Granacher et al. [4] framework aligned four stages (FUNdamentals, Learn to Train, Train to Train, Train to Compete) of the Balyi and Hamilton [2] model to chronological age, biological age, maturity, type of training and training adaptations. Early general models of athletic development recognized the importance of individualizing training to movement competency [2, 3], but they provided no guidelines on training prescription. Granacher et al. [4] have extended that concept by detailing how practitioners should use resistance training skill competency to determine the types of activities youth should engage in and how this should progress over time. Those activities are based on the popular forms of resistance training including plyometric and traditional strength training using bodyweight and external loading.

Plyometric training is a type of resistance training that refers to activities that initiate a rapid eccentric stretch of the muscle-tendon unit, resulting in a greater concentric contraction [6]. A model for plyometric training [6] is shown in the middle section of Figure 2.2 and aligns to the stages of the Balyi and Hamilton [2] LTAD model. However, recent literature recommends using technical competency and maturational status to progress training, rather than chronological ages typically associated with the LTAD stages [3, 4]. Several reviews suggest that as an athlete enters puberty, the intensity of resistance training and plyometrics should increase according to technical competency [4, 6]. Plyometric intensity is typically based on eccentric loading [6], so exercises should progress from minimal eccentric loading (jumps in place and standing jumps) to high eccentric loading (drop jumps) as technical competence increases. Irrespective of age and maturity status, technically incompetent athletes will likely benefit from learning how to hinge and properly load for a jump or only perform the concentric portion of a jump, before moving on to a countermovement jump (CMJ) and depth jumps.

Weightlifting training, a more specialized form of resistance training, has received far less attention than traditional strength and plyometric training in youth populations. Though there is one meta-analysis demonstrating the positive effect of weightlifting training on vertical jump performance [55], a lack of studies precludes any similar analyses with youth. Weightlifting interventions in youth athletes incorporate the snatch, clean and jerk and the various derivatives of each, in addition to common resistance training movements such as squats, presses and pulls [19-21]. Though research on the effects of weightlifting on athleticism is scarce, existing evidence supports the safety [21, 56] and potential benefits on motor skill performance in youth [19, 20]. Due to the limited amount of research on youth weightlifting, a small body of empirical evidence informs the existing models [5, 57, 58].

A peer-reviewed model for developing weightlifting in youth has been proposed and is shown towards the bottom of Figure 2.2 [5]. The model utilizes four stages that loosely align to the LTAD model of Balyi and Hamilton [2]: Fundamental Weightlifting Skills (FUNdamentals), Learning Weightlifting (Learning to Train), Training Weightlifting (Training to Train), and Performance Weightlifting (Training to Compete and Training to Win). Each stage is progressively more structured training and emphasis shifts from physical literacy - which involves the development of FMS and fundamental sporting skills [59] - to technical competence, to performance. It should be noted that although FMS is related to physical literacy, it is not a causal relationship. This means that just because a child is proficient at objectively measured FMS assessments does not mean he or she is physically literate, and vice versa. Within the model, using a top down approach to teaching weightlifting progressions is consistent with previous literature [19, 21]. This refers to learning movements starting from the mid-thigh, or power position, before progressing to the knee and finally the floor. Although the author provides suggested age ranges for stages, all athletes should enter the model at the earliest stage and progress according to technical competency as training age increases. However, if an athlete enters the model later in their development, he or she may progress through the stages faster as technical competency improves. The same premise remains for young athletes that demonstrate technical competency; they may progress through the stages at a faster rate. The United States and Canadian national governing bodies have also adapted the Balyi and Hamilton [2] model, despite its criticisms, to create weightlifting specific models [57, 58].

Fitness-specific models for athletic development

The evolution of athletic development models has resulted in the production of more detailed models of specific fitness components related to power [7], speed [8], agility [9] and aerobic fitness [10]. These models have informed the resistance training model of Granacher, Lesinski [4] and align to the stages of the DMSP [7, 10] or maturation [8, 9]. Figure 2.3

shows how the integration of models specific to different components of fitness can provide an integrated plan.

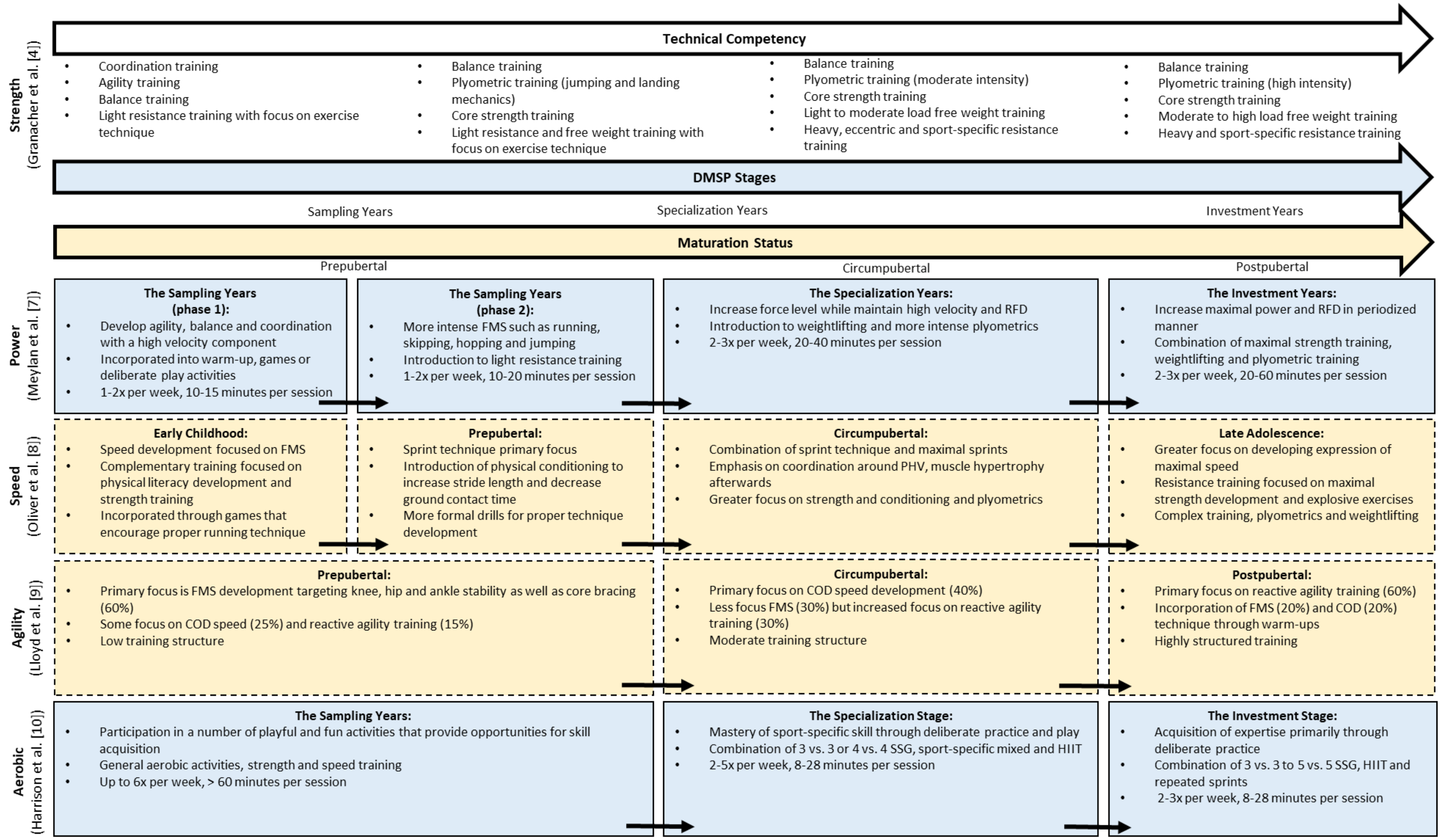

Figure 0.3. Summary of resistance training and power, speed, agility and aerobic models. The closed boxes are stages aligned to the DMSP while the dashed boxes are stages defined by maturation status. FMS = fundamental movement skills; RFD = rate of force development; COD = change of direction; SSG = small sided game; HIIT = high intensity interval training.

Strength

Strength is a primary outcome of resistance training but there is not a standalone model dedicated to it as a fitness component. Therefore, it is shown in relation to the [4] model. As discussed earlier, a secondary outcome of improving strength through resistance training is that its benefits transfers to all other fitness components [3]. Figure 2.3 also highlights that technical competency is task specific and coaches should program training methods accordingly. For example, a young athlete may be technically competent in power training methods but poor in agility training methods.

Power

Muscular power is an important component for athletic development due to its relationship with activities such as running [54], jumping [19] and sport-specific tasks such as track and field throws [60, 61]. An evidence-based model of power development was developed by Meylan et al. [7] based on a systematic review of 12 studies. The power development model overlaps with aspects from the resistance training models as strength training, plyometrics, and weightlifting are common forms of power training.

The model of power development uses stages from the DMSP to organize four variables of power training: integration, session duration, session frequency, and block duration. The power development model also begins to address some of the lack of detail on programming from previous resistance training models. The sampling years are broken into two phases (age 5-8, age 9-12) due to the many mental and physical changes during this age period. The primary goals for this phase of training are to develop FMS, agility, balance and coordination with high velocity components. This reflects the common philosophy of other general and specific models to prioritize the development of fundamental movement skills before progressing to more complex and demanding tasks. Proper jumping and landing technique should be taught to maximize explosive training and reduce the risk of injury associated with deficiencies in load absorption [62]. During the specialization years (age 13-15), an increase in volume, intensity, movement complexity and the addition of weightlifting movements to improve powerful triple extension of the lower body should accompany training, provided technical competency is sufficient. During the investment years (16+), training should continue to develop maximal strength, as well as more sport-specific movements and higher intensity plyometric training.

Speed

The differences in speed between players in relatively high and low levels of competition demonstrate the importance of speed for athletic development [63, 64]. There is also a strong relationship between sprinting and other measures of performance such as jumping and strength [65, 66]. Due to the importance of speed on athletic performance, there are several meta-analyses [54, 67] and reviews [68] on youth speed development. A series of guidelines provided in a narrative review by Oliver et al. [8] highlighted the importance of FMS and resistance training to maximize speed development. As with power training, speed training incorporates a large emphasis on different forms of resistance training.

In the review of Oliver et al. [8], stages of speed development were defined by maturational status and training age, rather than chronological age, which aligns to the YPD model, and included early childhood (age 0-7), prepubertal (age 7-12), circumpubertal (age 11-15 males, age 12-15 females) and late adolescence (age 16+ males, age 15+ females). In line with the YPD model, the authors suggest that training during early childhood should focus on FMS and strength training through active play and games that encourage good running technique. The circumpubertal stage should focus on sprint technique and maximal sprints for speed development and while adding hypertrophy to the resistance training program to maximize any structural adaptations associated with increased force production and thus, greater stride length [69]. Lastly, the late adolescence stage features maximal sprints and complex training methods, which have been shown to improve repeated sprint ability and change of direction (COD) in youth [70, 71]. Throughout childhood and adolescence, the pathway suggests that given the known transfer of non-specific sprint training to speed, complementary resistance training supports speed development [54, 68]. The guidelines provided by Oliver et al. [8] organize training stages by maturation with training age as a key component, as technical competency should always drive progression. This model further highlights the importance of FMS development prior to more complex non-specific training methods (e.g. plyometric and strength training). Furthermore, developing FMS through free play and small-sided games may enhance the coupling of FMS to more complex sport skills, and should be included throughout development due to links with athletic motor skills and long-term effects of physical activity [72, 73].

Agility

The development of agility is important for most field and court team sports due to the need to react and change direction in reaction to external stimuli. Agility refers to a rapid whole-body movement with change of velocity or direction in response to a stimulus. Since true agility must require a response to an external stimulus [74], COD speed is the variable typically assessed instead throughout the literature. Several systematic reviews have examined the effect of resistance training on agility [75, 76] and COD [11] in youth. Many other experimental studies have investigated the relationship of COD with other measures of athletic performance [63, 77, 78] as well as the trainability of COD using both specific and non-specific training methods [48, 79]. Although not proposed as a standalone model, a narrative review by Lloyd et al. [9] proposed three main components of agility training (FMS, COD speed, and reactive agility training) and attempted to show how training focus could change with increases in technical competency (Figure 2.3).

Adolescent awkwardness refers to the temporary loss in motor coordination during a period of rapid growth and is characterized by greater movement variability and decreased movement proficiency [80]. Athletes experiencing "adolescent awkwardness" during the circumpubertal years may need coaches to give special attention to body position and technique as they learn to coordinate their longer limbs. Although the training percentage breakdown are arbitrary example values, the concept of progressing from FMS to more complex training modes throughout development is central to athletic development [3, 4] and other fitness specific models [7, 8, 10]. Lloyd et al. [9] also suggest strength, plyometric, and combined training are effective in improving COD speed and practitioners should implement these appropriately alongside agility training. This concept is similar to the YPD model's approach to simultaneously training all fitness components. Additionally, as with speed, games and free play can serve as effective methods for coupling FMS with more complex sport skills.

Aerobic fitness

Aerobic fitness is an important component in team sport performance to help sustain a high work rate throughout a match [81], to aid with recovery [82] and to help maintain quality technical and tactical decision making [83]. An evidence-based model for aerobic fitness development in youth team sport players was developed by Harrison et al. [10] from a systematic review of 14 studies.

This model aligns to the developmental stages of the DMSP. Harrison et al. [10] proposed that training during the sampling stage should be fun and engaging and include strength and speed components, similar to previous recommendations given in the YPD model [3]. During the sampling stage, sessions should be no longer than 60 minutes and performed up to 6 times per week through forms of deliberate practice and/or play. Training during the specialization stage should last between 8-28 minutes up to five times per week and should focus on mastery of sport specific skills through small-sided games (SSG) and high-intensity interval training (HIIT). Following previous recommendations [14, 49], it is suggested that training load be monitored as repetitive loading during the adolescent spurt can increase risk of overuse injuries [39]. During the investment stage, the primary focus is improving performance in competition. In addition to small-sided games, Harrison et al. [10] recommends high-intensity interval training and/or sprint training one to three times per week.

A requirement of training at all stages is that some or all of the work should be completed at an average high-intensity of ≥ 85% HR max to promote gains in aerobic fitness [84]. The need for youth to engage in high-intensity exercise to improve their maximal oxygen uptake is in agreement with previous reviews [85, 86]. Although there is no mention of resistance training in the model, evidence suggests resistance training may improve muscular endurance performance in youth [15, 87, 88] and thus should remain a central component of any athletic development program. Because this model aligns to the DMSP, stages are defined by participation rather than biological or training age. Due to the influence of maturation on physiological adaptations, practitioners should consider maturity status when prescribing training methods for youth. For instance, as prepubertal youth are more reliant on aerobic metabolism, they may need to train at relatively higher intensities to experience training adaptations [89].

Conclusion

The growth of youth sport and physical training as a method to improve health has led to a growing interest in LTAD. Early general models suggest sampling multiple activities from an early age to develop a variety of movement patterns, as well as considering the interaction of maturation on the training response. These models provided stages for subsequent guidelines and conceptual models regarding resistance training modalities such as plyometric training and weightlifting. Furthermore, subsequent models have used existing frameworks to provide more detail into developing specific fitness components throughout childhood and adolescence. The models and guidelines presented in this paper should help direct coaches and practitioners to proper application of LTAD programs.

Chapter 3: Integrating Resistance Training into High School Curriculum

This chapter comprises the following article published in the *Strength and Conditioning Journal*.

Reference:

> Pichardo A.W., Oliver J.L., Harrison C.B., Maulder P.S., & Lloyd R.S. (2019). Integrating resistance training into high school curriculum. *Strength and Conditioning Journal*, 41(1), 39-50.

Preface

The review of literature in Chapter 2 suggests youth should engage in a variety of activities and resistance training methods, including plyometrics and weightlifting. This chapter aims to provide an applied example of how practitioners can successfully implement a CRT (traditional strength training, plyometrics, and weightlifting), into secondary school curriculum. Specifically, a periodized plan suitable for children entering secondary school with zero training age is provided. Additionally, information regarding coach qualification, pedagogical considerations, and providing valuable feedback is presented to assist practitioners with delivering the program.

Introduction

Resistance training in youth, which includes children and adolescents (age 11-18), can provide many physical [11] and social and emotional benefits [90] and refers to activities used to improve health, fitness and performance using body weight, machines, free weights, elastic bands and medicine balls [50]. Globally, declines in neuromuscular fitness [91, 92], fundamental movement skills [93] and physical activity [94] likely contribute to the high rate of sport related injury in youth [95]. Furthermore, the NSCA's position statement on LTAD suggests all youth, not only athletes, should participate in long-term exercise programs that promote physical development to prevent injury and maintain a healthy lifestyle [14]. An increasingly common and effective method for improving youth physical development involves the use of resistance training in school curriculum [96]. This requires a coordinated, periodized approach that goes beyond simply planning for a single school term and meets the World Health Organization's recommendations on physical activity for health that suggest children aged 5-17 years should engage in vigorous intensity activities that strengthen muscle and bone two to three times per week [97]. Embedding resistance training that stimulates positive muscle and bone adaptation into school curriculum would help achieve this recommendation, as previous research has found higher rates of bone development in youth weightlifters and gymnasts [98, 99].

An early position statement from the American Academy of Pediatrics [100] cautioned against the use of resistance training and weightlifting in pre-adolescents due to a high injury rate. However, resistance training is now recognized internationally as a safe and effective training mode for children and adolescents [49]. Faigenbaum and Myer [101] suggest that resistance training injuries are often accidental and can be prevented with qualified instruction. Surveys conducted by Hamill [56] also suggest that injuries related to resistance training are much lower than other common team sports, such as soccer, rugby and basketball. Additionally, in academy and school boy rugby training, injury incidence from weight training was below that for all types of rugby-specific training activities, as well as endurance training [102].

Although resistance training often refers to traditional strength training (common gym movements such as squat, lunges, bench press performed at a moderate velocity with low to high volume and intensity depending on training goal), other forms of resistance training such as plyometric and weightlifting training (snatch, clean and jerk and their derivatives) have also been shown as effective means of improving physical performance of youth [19, 20]. A meta-analysis by Lesinski et al. [11] demonstrated moderate effects of resistance training on strength and jump performance and small effects on linear sprint, agility and sport-specific performance in youth, highlighting the notion that resistance training effectively improves multiple fitness components. Furthermore, a recent meta-analysis by Behm et al. [54] highlighted the specificity of resistance training effects on athletic performance in youth, showing greater gains in jump performance with power training (plyometrics) and greater strength gains from traditional strength training (external resistance or bodyweight). Finally, findings from Channell and Barfield [20] and Chaouachi et al. [19] indicate that weightlifting provides greater improvements in vertical jump height after six and 10-week interventions in post-PHV (age 15.9 ± 1.2 years) and prepubescent athletes (age 10-12 years), respectively. Therefore, a mixed methods approach to strength and power development for youth is most beneficial, though the adaptations are likely specific to the type of training performed.

The long-term structured approach needed for athletic development is supported by the NSCA position statement [14], several meta-analyses [11, 15] and athletic development models [2-4] and a commentary on multiyear planning for the high school athlete [13]. Furthermore, Faigenbaum and Meadors [103] suggest structured training programs delivered by qualified coaches are needed to promote physically literate youth. Physical literacy is an increasingly popular term that refers to the ability to move with competence and confidence in a variety of physical activities in multiple environments that benefit the holistic development of a person [104]. Youth are less likely to become physically literate if they are not afforded the opportunity to learn and perform movements in an increasingly challenging environment. Younger children engage in larger amounts of deliberate play, which may occur in a relatively unstructured manner [1] and although unstructured play is important in the wider context of the overall physical activity experience, children typically begin to shift from high levels of deliberate play to deliberate practice around the age they enter high school [1]. Cumulatively, these concepts support the need for youth to follow a periodized plan [105] aimed to promote both physical literacy and athletic development. Several meta-analyses have demonstrated a positive relationship between intervention duration and resistance training effects [106], showing that longer training periods are more effective in realising gains in muscular strength [11, 15] and power [7]. Additionally, Lesinski et al. [11] concluded that improving strength for youth using resistance is most effective when programs lasted for at least 23 weeks. However, Meylan et al. [7] reported that the number of sessions, as opposed to intervention length, demonstrated a clearer difference in program effectiveness and should also be considered in program design. In a series of long-term studies, two years of resistance training resulted in improvements in speed [46] and COD performance [48]. Most impressive, however, were the large gains in back squat strength (100-300%) following exposure to a similar, two-year training intervention compared to the control groups (20-60%) [47]. Thus, youth have the capacity to make large gains in strength and athleticism when they ascribe to long-term, systematic training.

Resistance training for youth is becoming more prevalent in high schools as the safety and benefits of this type of training are gaining acceptance [96]. However, there is a clear lack of specific guidance on programming for youth [12]. A survey showed that high school physical education teachers and sport coaches, as well as university physical education students, may lack the required knowledge and experience to design, implement and supervise youth resistance training programs [12]. Therefore, the purpose of this article is to provide coaches and educators an example of how resistance training can be effectively implemented into secondary-school curriculum, as well as highlight some of the challenges faced by coaches operating in the high school setting.

Periodization models

The need for long-term resistance training programs corresponds to a need for periodization of training. Periodization refers to a planning paradigm in which training interventions are structured to maximize athletic development in accordance with the person's needs [107] and reduces the likelihood of overtraining or monotony in youth [105]. Several forms of periodization exist: traditional (classic or linear), block and undulating (daily or weekly). Traditional periodization organizes training into a multi-year plan, annual plan, macrocycle, mesocycle (medium-sized training cycles; typically two to six weeks), microcycle (small-sized training cycles; typically one week), training day, training session and training unit [108]. It also typically involves a gradual increase in intensity with a decrease in volume. Linear periodization includes training several fitness components simultaneously and is ideal for a single-peak within a year. Block periodization, on the other hand, is organized into accumulation, transmutation and realization mesocycle-blocks and is more common in high-level athletes that require several yearly peaks [109]. These blocks utilize highly concentrated loads for a limited amount of fitness components as opposed to training several simultaneously. Lastly, daily and weekly undulating periodization models are based on variations of volume and intensity and are thought to provide better performance gains through a more varied training stimulus [110].

Research suggests both block and daily undulating periodization (DUP) are effective in improving strength and power in both adults [111] and adolescents [112]. However, a study by Painter et al. [113] comparing a 10-week traditional versus DUP intervention in collegiate track and field athletes showed that both groups achieved similar gains in performance but the block periodization group completed less volume overall, suggesting traditional periodization is more efficient. Additionally, the use of repetition maximum (RM) ranges to prescribe intensity, as often seen in a DUP approach, may not be suitable for youth with a low training age trying to maintain technical competency. Lastly, a traditional approach may be superior to a block approach for young athletes wanting to develop a variety of fitness components simultaneously. Above all, proper vertical integration – how training factors interact with each other within a given period – and horizontal sequencing – how each factor is sequenced over time - is essential to achieving desired training outcomes [107, 114].

Applying theory to practice: an applied working example from the New Zealand high-school system

Within a school setting, the structure of the training program must accommodate for academic events, holidays and daily timetable requirements. Therefore, the academic calendar may dictate the length of mesocycles based on school holidays or breaks. Fortunately, evidence shows even short training periods can be effective in promoting athleticism in youth [20, 115], but the accumulation of research shows longer programs [11, 15, 46] with more sessions [7] are most effective. Nevertheless, an academic year, which may last between 35-40 weeks, should provide a sufficient period to stimulate meaningful adaptations for strength, power, speed and aerobic capacity in both children and adolescents.

The example annual plan (Figure 3.1) was developed using a traditional periodization approach for high school students in New Zealand and delivered during curriculum time by a Certified Strength and Conditioning Specialist within the school. The program aimed to improve athletic motor skill competencies (AMSC) to help prevent youth experiencing a proficiency barrier [116], where a lack of strength and skill may prevent youth from engaging in physical activity. This inherently requires some level of coaching and structure. The program was designed for students who have participated in sport and developed some level of competency of FMS (locomotion, balance and stability) but have little to no training age with regards to resistance training. Anecdotally, this is a common scenario within the high school setting. It is worth noting that just because a child takes part in sport does not mean that they have competent athletic motor skills. For example, Parsonage et al. [117] found that regional academy rugby players had relatively low movement competency, which may hinder their progression to more advanced training methods. This supports the idea that all youth, irrespective of their involvement in sport, will benefit from resistance training. Within a multi-year plan, this annual plan could serve as the first or second year, depending on a child's capabilities. Given the levels of hierarchal planning needed for long-term periodized programs, this example provides a general overview at the macrocycle level before progressing to an in-depth example of an individual training session.

<table>
<tr><th>Week</th><th>30/01/17</th><th>06/02/17</th><th>13/02/17</th><th>20/02/17</th><th>27/02/17</th><th>06/03/17</th><th>13/03/17</th><th>20/03/17</th><th>27/03/17</th><th>03/04/17</th><th>10/04/17</th><th>17/04/17</th><th>24/04/17</th><th>01/05/17</th><th>08/05/17</th><th>15/05/17</th><th>22/05/17</th><th>29/05/17</th><th>05/06/17</th><th>12/06/17</th><th>19/06/17</th><th>26/06/17</th><th>03/07/17</th><th>10/07/17</th><th>17/07/17</th><th>24/07/17</th><th>31/07/17</th><th>07/08/17</th><th>14/08/17</th><th>21/08/17</th><th>28/08/17</th><th>04/09/17</th><th>11/09/17</th><th>18/09/17</th><th>25/09/17</th><th>02/10/17</th><th>09/10/17</th><th>16/10/17</th><th>23/10/17</th><th>30/10/17</th><th>06/11/17</th><th>13/11/17</th><th>20/11/17</th><th>27/11/17</th><th>04/12/17</th><th>11/12/17</th></tr>
<tr><td>Academic Term</td><td colspan="11">Term 1</td><td colspan="2" rowspan="8">Term break</td><td colspan="10">Term 2</td><td colspan="2" rowspan="8">Term break</td><td colspan="10">Term 3</td><td colspan="2" rowspan="8">Term break</td><td colspan="9">Term 4</td></tr>
<tr><td>Academic Week</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>8</td><td>9</td><td>10</td><td>11</td><td>12</td><td>13</td><td>14</td><td>15</td><td>16</td><td>17</td><td>18</td><td>19</td><td>20</td><td>21</td><td>22</td><td>23</td><td>24</td><td>25</td><td>26</td><td>27</td><td>28</td><td>29</td><td>30</td><td>31</td><td>32</td><td>33</td><td>34</td><td>35</td><td>36</td><td>37</td><td>38</td><td>39</td><td>40</td></tr>
<tr><td>Mesocycle</td><td rowspan="6">Testing Battery</td><td colspan="5">1</td><td colspan="5">2</td><td colspan="5">3</td><td colspan="4">4</td><td rowspan="6">Testing Battery</td><td colspan="5">5</td><td colspan="5">6</td><td colspan="4">7</td><td colspan="4">8</td><td rowspan="6">Testing Battery</td></tr>
<tr><td>Microcycle</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>8</td><td>9</td><td>10</td><td>11</td><td>12</td><td>13</td><td>14</td><td>15</td><td>16</td><td>17</td><td>18</td><td>19</td><td>20</td><td>21</td><td>22</td><td>23</td><td>24</td><td>25</td><td>26</td><td>27</td><td>28</td><td>29</td><td>30</td><td>31</td><td>32</td><td>33</td><td>34</td><td>35</td><td>36</td><td>37</td></tr>
<tr><td>Weight Room Emphasis</td><td colspan="10">Athletic Motor Skill Competencies</td><td colspan="9">Strength endurance</td><td colspan="10">Max Strength</td><td colspan="8">Strength speed</td></tr>
<tr><td>Weight Room Training Goals</td><td colspan="10">Introduce basic movement skills in a variety of contexts using bodyweight and light resistance.</td><td colspan="9">Improve work capacity using introductory exercises and light to moderate loads.</td><td colspan="10">Increase force production using moderate to heavy loads and foundation movements.</td><td colspan="8">Develop explosive power using moderate to heavy loads.</td></tr>
<tr><td>Field/Court Emphasis</td><td colspan="10">Acceleration / COD</td><td colspan="9">Acceleration / COD</td><td colspan="10">Maximum Speed / Agility</td><td colspan="8">Maximum Speed / Agility</td></tr>
<tr><td>Field/Court Training Goals</td><td colspan="10">Introduce basic sprint and COD positions using games and short distance drills</td><td colspan="9">Develop accelerative ability and COD speed using short distances</td><td colspan="10">Improve maximal speed and agility using moderate distances and agility games</td><td colspan="8">Increase maximal speed and agility using maximal sprints and reactive agility training</td></tr>
</table>

Figure 0.1. A sample macrocycle for New Zealand and Australian school systems. COD = change of direction.

Macrocycle

This plan includes two mesocycles, or medium-sized training periods, each school term, for a total of eight across the academic year. The training emphasis for each school term is delivered over two, four to five week mesocycles. Emphasizing certain training qualities over two separate mesocycles each term allows for some variation in intensity, volume and exercise selection which may help reduce training monotony. For example, an early focus on AMSC during term one provides low load and requires minimal equipment but can be developed using different exercises each mesocycle. As training age and technical competency increase throughout the year, more complex movements and greater intensities (>80% 1RM) can be used in order to promote ongoing adaptations in muscular strength and power [11]. The example plan accounts for sessions on two non-consecutive days per week, in accordance with the school's curriculum and training frequency and recovery recommendations [50, 88]. Long-term youth training programs should aim to develop all athletic qualities, so using resistance training combined with other training stimuli to promote athletic development is suggested [3, 4]. Therefore, each session provides weight room-based exercises and field or court-based speed and agility exercises. These are done within the same session to deliver more frequent exposures to several stimuli, as opposed to only once per week.

Several times a year, students complete various tests to assess motor skill performance and monitor growth rates. Coaches can use this data to evaluate the effectiveness of the program and modify exercise volume or complexity during periods of rapid growth, as youth are more prone to overuse injuries in this time [118]. Additionally, using a combination of a weekly questionnaire to determine training load and a daily wellbeing questionnaire to assess readiness to train, as suggested by Read et al. [23], may help coaches manipulate training load to reduce the risk of non-functional overreaching and overtraining [119]. For example, reducing volume, load or exercise selection during the season may help the athlete cope with the cumulative stressors of life in sport. Any performance tests used should be specific to the training and may assess qualities such as movement competency, strength, power, speed and aerobic fitness. Monitoring growth rates or maturation can be achieved using the Mirwald et al. [120] or Khamis and Roche [121] equations. Evaluating progress of athletic motor skills and maturation is advocated by the NSCA [14] and International Olympic Committee youth athletic development position statements [122] and coaches typically assess five fitness components and occur three to four times per year [123]. The example plan supports these suggestions as the training is designed to improve movement competency, strength, speed, power and aerobic fitness and assessments are implemented on three occasions throughout the year – at the start, midpoint and end of the year.

Mesocycle

A mesocycle provides more detailed planning for each training block and generally last between two to six weeks [107]. The most common mesocycle setup is a traditional 3:1 (3 loading:1 unloading) microcycle loading structure. Haff [105] provides several other loading structures (3:1, 3:2, 4:1, 4:2) that are dependent on an athlete's training age and ability to recover from training. In a high school setting, mesocycle length and structure may also depend on breaks or holidays. Figure 3.2 shows example content from the first term (mesocycle one and two) of the example annual plan.

Week	30/01/17	06/02/17	13/02/17	20/02/17	27/02/17	06/03/17	13/03/17	20/03/17	27/03/17	03/04/17	10/04/17
AcademicTerm	Term 1										
AcademicWeek	1	2	3	4	5	6	7	8	9	10	11
Mesocycle	Testing Battery	1					2				
Microcycle		1	2	3	4	5	6	7	8	9	10
Weight Room Emphasis		Athletic Motor Skill Competencies									
Volume		1-2 sets; 8-12 reps	2-3 sets; 8-12 reps	2-3 sets; 8-12 reps	1-2 sets; 6-10 reps	2-3 sets; 6-10 reps	2-3 sets; 8-12 reps	2-3 sets; 8-12 reps	1-2 sets; 6-10 reps	2-3 sets; 6-10 reps	2-3 sets; 6-10 reps
Intensity		Low	Low	Low	Moderate	Moderate	Low	Low	Moderate	Moderate	Moderate
Number of Exercises		6	6	6	8	8	8	8	10	10	10
Field/Court Emphasis		Acceleration / COD									
Volume		1-2 sets; 5-10 reps	2-3 sets; 5-10 reps	2-3 sets; 5-10 reps	1-2 sets; 5-12 reps	2-3 sets; 5-12 reps	2-3 sets; 5-10 reps	2-3 sets; 5-10 reps	1-2 sets; 5-12 reps	2-3 sets; 5-12 reps	2-3 sets; 5-12 reps
Intensity		Low	Low	Low	Moderate	Moderate	Low	Low	Moderate	Moderate	Moderate
Number of Exercises		10	10	10	8	8	10	10	8	8	8

Figure 0.2. The first two mesocycles from the annual plan showing training variable guidelines. COD = change of direction.

The first two mesocycles are primarily focused on using bodyweight or light resistance for the development of AMSC, as described by Moody et al. [124]. The AMSC include eight components: lower body unilateral; lower body bilateral; upper body pushing; upper body pulling; anti-rotation and core bracing; jumping, landing, and rebounding mechanics; throwing, catching, and grasping; acceleration, deceleration, and reacceleration. The example plan addresses most of these skills using one to three sets of 5-12 repetitions of bodyweight and light resistance movements aimed to improve technical competency in common resistance training movements and basic plyometric exercises. Due to the relatively low load used during this training period and the generally low training age of most students, an unload week to allow athlete recovery is not needed at the end of the each mesocycle. However, the volume is typically lower during the first week of each mesocycle to allow for explanation of new exercises and coaching cues.

After three school terms inclusive of six to seven sequential mesocycles of training, technically competent students may be able to (and need to) perform high force movements (e.g. loaded back squats) and high velocity movements (e.g. jumps and sprints) to promote ongoing adaptations. Figure 3.3 shows example content from term four (mesocycles seven and eight) from the example annual plan.

Week	16/10/17	23/10/17	30/10/17	06/11/17	13/11/17	20/11/17	27/11/17	04/12/17	11/12/17
AcademicTerm	Term 4								
AcademicWeek	32	33	34	35	36	37	38	39	40
Mesocycle	7				8				Testing Battery
Microcycle	30	31	32	33	34	35	36	37	
Weight Room Emphasis	Strength Speed								
Volume	1-2 sets; 4-6 reps	2-3 sets; 4-6 reps	3-4 sets; 4-6 reps	2-3 sets; 2-4 reps	4-5 sets; 2-4 reps	4-5 sets; 2-4 reps	3-4 sets; 2-4 reps	2-3 sets; 2-4 reps	
Intensity	Low	Moderate	High	Deload	Low	Moderate	High	Deload	
Number of Exercises	5	5	5	4	4	4	4	3	
Field/Court Emphasis	Maximum Speed / Agility								
Volume	1-2 sets; 3-8 reps	2-3 sets; 3-8 reps	2-3 sets; 3-8 reps	2-3 sets; 2-6 reps	4-5 sets; 3-8 reps	4-5 sets; 3-8 reps	4-5 sets; 3-8 reps	2-3 sets; 2-6 reps	
Intensity	Low	Moderate	High	Deload	Low	Moderate	High	Deload	
Number of Exercises	6	6	6	5	6	6	6	5	

Figure 0.3. The last two mesocycles from the annual plan.

Research has shown that a combination of high force and high velocity exercises is superior to one or the other exclusively [125] and can successfully be performed within the same training sessions to develop a range of fitness qualities [17, 18]. The range of exercise intensities and velocities in mesocycles seven and eight reinforces this mixed methods (high-force and high-velocity movements) approach advocated by Haff and Nimphius [126]; one to five sets of two to eight repetitions was used to allow for higher loading and more interset recovery. However, if a student is lacking proper movement, coaches should continue to prescribe less-complex exercises until a student demonstrates competency.

Microcycle

A microcycle typically lasts 5-10 days, with a week being the most common length. Figure 3.4 shows an example microcycle from the annual plan that includes two resistance training sessions a week, which has been shown to be sufficient in eliciting improvements in young males [87]. However, though session frequency and duration would depend on a particular school's timetable, these variables may not change over the course of a year and would not depend on technical competency or training age like other variables may. The microcycle content, however, may differ depending on a student's technical competency, whether they are in a sport season, academic pressures (e.g. exam periods) and their overall workload.

Academic Term	Term 4			Mesocycle	8		
Academic Week	36			Microcycle	32		
Weight Room Emphasis	Strength Speed						
Field/Court Emphasis	Maximum Speed/Agility						
Day	Monday, 16/10/2017	Tuesday, 17/10/2017	Wednesday, 18/10/2017	Thursday, 19/10/2017	Friday, 20/10/2017	Saturday, 21/10/2017	Sunday, 22/10/2017
AM	OFF	Clean Derivative Squat UB H Push UB H Pull V Plyometrics Acc. / Linear Speed	OFF	OFF	OFF	Competition	OFF
PM	OFF	Sport Training	OFF	Sport Training	Snatch Derivative Hinge UB V Push UB V Pull H Plyometrics COD / Agility	OFF	OFF

Figure 0.4. Example microcycle with school curriculum athletic development sessions, as well as extracurricular sport training and competition.

Training Session

In the applied example, the training session lasts one class period and consists of several training units, such as the warm-up, weight-room and field or court-based portion. Due to time constraints, sessions typically last between 45-60 minutes in the school setting [123], which are still in accordance with youth resistance training recommendations [49]. Logistics must consider transition time to get students changed into appropriate training gear and perform a thorough warm-up. The warm-up provides a unique opportunity to introduce exercises and games that help promote movement competency in a fun, less structured way. In fact, the warm-up itself can provide a physical stimulus that challenges movement competency and strength [127] and may be beneficial in other scenarios when a full session is not possible.

To manage relatively large class sizes, coaches with an appreciation of movement competency can choose a progressive or regressive task that provides a suitable challenge for each student, or group of students, based on technical proficiency, time of year or maturation status. Tasks can be manipulated using a variety of categories to create more or less challenging versions of the same task: task complexity (simple to complex), nature of exercise stimulus (pre-planned to reactive), motor skills per exercise (single to multiple), direction of movement (linear to multidirectional), repetition velocity (slow to fast), resistance (unloaded to loaded), movement type (static to dynamic), structure of program (exploratory to highly structured). These task manipulation categories can apply to all types of training. For example, students with low competency for a horizontal push pattern may perform a band-assisted push-up; students with average competency may perform a standard push-up; while students with high competency may perform a weighted push-up or an alternative progression (e.g. feet raised, a narrower hand position or an explosive push-up with hands leaving the ground). Additionally, in a sprinting task, less competent students may focus on technical drills using submaximal intensity while more competent students may perform maximal sprints with external resistance.

Shown below in Figure 3.5 is an example session that accounts for different levels of movement competency using a bronze, silver and gold approach, similar to a study by Meylan et al. [128] in age 11-15 year old males. Since competency might vary between movement patterns, programming methods should allow students to perform each exercise at the appropriate competency level. For example, if a student is competent on a squat pattern, but not a horizontal push, he or she may perform the gold level squat but bronze level horizontal push.

	Exercise Type	Bronze	Silver	Gold	Volume
Field/Court Emphasis	Plyometric	Countermovement Jump	Depth Jump (low)	Depth Jump (high)	3 sets; 3 reps
		SL Drop (stick)	SL Jump	SL Depth Jump	3 sets; 3 reps/leg
		Low-hurdle Hop (rapid)	High-hurdle Hop (stick)	High-hurdle Hop (rapid)	3 sets; 5 reps/leg
	Speed	30 m Sprint (submaximal intensity; maximum speed technique focus)	30 m Sprint	30 m Sled Sprint	3 reps
		10 m Sprint (submaximal intensity; acceleration technique focus)	10 m Sprint	10 m Sled Sprint	3 reps
		Float-Fly-Float (10-20-10)	Fly-Float-Fly (10-20-10)	Fly-Float-Fly (10-30-10)	3 reps
Weight Room Emphasis	Clean Variation	Hang Clean	Clean from Low Block	Clean	5 sets; 3 reps
	Clean Variation	Clean Pull (pause at knee & power position)	Clean Pull (<100% 1RM Clean)	Clean Pull (>100% 1RM Clean)	5 sets; 3 reps
	Squat	Goblet Squat	Box Back Squat	Back Squat	5 sets; 3 reps
	Horizontal Push	Push-up	DB Bench Press	Bench Press	5 sets; 3 reps

Figure 0.5. Sample session adaptable for athletes of varying competency levels. DB = dumbbell; SL = single-leg.

There are measurement tools to formally assess basic bodyweight movements [129-132] and resistance training competency of students [133, 134]. However, the 'art' of assessing movement and hopefully correcting potential movement limitations in real-time is a critical skill set of successful coaches. Examples of poor movement competency is usually characterized by excessive spinal flexion or extension, instability, uncontrolled tempo and/or patterns associated with injury risk (such as knee valgus) [134]. In contrast, students displaying technical competency often use a controlled tempo with stability displayed throughout the motion and joints tracking in the correct direction. These deficiencies in movement competency could be due to neuromuscular, strength and/or mobility limitations [134], so coaches must first identify the cause for the limitation before implementing strategies for improvement. Additionally, there may be situations where a coach may want to temporarily regress a movement after a long school holiday, or more importantly, when kids are going through a growth spurt and may experience adolescent awkwardness.

Delivering the program

Equally important to the content is the delivery of the training program to the students, as suggested by pillar ten of the NSCA position statement on LTAD [14]. Furthermore, Faigenbaum and Meadors [103] highlight the importance of coaches understanding the process of development, fostering creativity and being patient in order to maximize youth development. School administrators should ensure that coaches or teachers have an awareness of pediatric exercise science and are properly qualified and certified to work with youth in an athletic development setting. Qualified coaches can then use their knowledge to provide feedback techniques that elicit gains in skill acquisition and subsequently, athletic performance. Additionally, qualified teachers or coaches can help an athlete navigate athletic development during the transitional high school years by taking an athlete-centered approach and being aware of symptoms associated with overtraining.

Qualification

Several position statements [14, 49] recommend hiring qualified strength and conditioning coaches with appropriate certifications (e.g. CSCS or USAW) for the high school setting. These recommendations are supported by a study by Coutts et al. [135] that found that 12 weeks of resistance training under a strength and conditioning coach improved training adherence and total body strength more than an unsupervised training group. Research has also revealed that most resistance training injuries in youth are due to accidents [136] and unsupervised training [137]. Thus, qualified professionals can elicit improvements in performance and decrease the risk of resistance training related injury and should therefore be present in all high school weight rooms.

Pedagogical considerations for the high school setting

There are several factors that may help with the integration of strength and conditioning into high school curriculum. For instance, a constraints-led approach can be used to manipulate environmental, task and individual constraints to better facilitate skill development [138]. Environmental constraints refer to the physical and social factors contributing to movement skill acquisition and are important in creating a motivational climate that students enjoy. Enjoyment of physical activity depends on the student’s perception of the motivational climate [139]. In a survey of year nine Finnish students (n = 4397), a task-oriented environment, relatedness and autonomy were positively related to enjoyment of PE classes. Furthermore, Halperin et al. [140] suggest that giving autonomy to athletes by letting them make choices regarding training variables can increase motivation and performance. Another survey of high school athletes (n = 128) indicated that athletes that perceived a high caring and task-involving climate in their strength and conditioning program reported high effort, enjoyment, competence, intrinsic motivation and commitment [141] which demonstrates the importance of creating a beneficial training environment. Chamberlin et al. [141] offer tips for creating a caring and task-involving climate, such as praising athletes for their high effort and improvement, fostering cooperation among athletes, emphasizing that mistakes are part of the learning process, highlighting an athlete's role within a team and encouraging athletes to treat other with kindness and respect. Lastly, evidence has shown that a year-long intervention aimed to change motivational climate to more task-involving and less ego involving can positively affect high school students attitudes towards exercise and sport participation [142]. Together, these studies suggest that environment is an important but modifiable constraint that is integral to implementing resistance training successfully.

Qualified coaches should be able to modify activities to ensure skill can be developed in variety of contexts across different age and ability levels. Practitioners can impose task constraints to help students learn movements by solving problems in an exploratory manner. Task constraints refer to the goal of the task, rules of the activity and implements used during the skill acquisition process and are one of the most common types of constraints used. Task constraints are easily implementable and can include the simple addition of a bean-bag placed on top of the head during a squat will keep a student's head and torso more upright; placing a foam-roller or stick behind an athlete to reach their hips back on a hinge pattern; or performing a squat facing a box or wall to keep the heels from coming off the floor [143]. Research by Verhoeff [144] showed that adding task constraints can improve power clean bar path, which may improve 1RM performance.

Performer, or individual, constraints refer to the physical, physiological, cognitive and emotional make-up of the learner. Although mostly unchangeable, coaches should be cognizant of individual constraints as they may influence what a child can do or how they do it. For example, an athlete with longer legs may utilize a wider squat stance. Physical constraints may be somewhat determined by genetics, but a coach can help improve certain physiological factors such as strength, power and movement skill with a periodized training program.

Providing valuable feedback

Different methods of providing feedback can be beneficial in positively altering movement mechanics. Jeraj et al. [145] reported that methodological knowledge (details and approaches that constitute the steps for performing a specific movement) and visual perspective (where a coach is viewing the movement in relation to where an athlete is performing it) were two of the most important feedback factors that might influence the error-correction process. Therefore, a coach must know what common errors he or she is looking for in a movement, and view movements from different perspectives to get a clear picture of what is happening. For example, in order to observe technical deficiencies in a squat pattern (e.g. forward trunk lean, knee valgus), coaches should view movements from multiple planes of motion (e.g. sagittal and frontal). Additionally, visual experience (accumulation of specific observations and spectatorships of a movement) was listed as the most frequently used factor for providing feedback [145], suggesting that accuracy in error detection and correction may improve with increased experience.

Another important factor when providing feedback is whether the focus of attention is directed *internally* towards bodily movements or functions, or *externally* towards the movement outcome or an external object [146]. Several studies have demonstrated greater performance in isometric mid-thigh pull (IMTP) [147], standing long-jump [148], and sprint [149] performance with an externally focused compared to an internally focused attention. Recently, a review from Winkelman [150] highlighted three characteristics of external cues (i.e. distance, direction and description) that should be considered when providing feedback to individuals. *Distance* refers to a focus of attention distal or proximal in relation to a fixed point; *direction* refers to a location that is towards or away from a fixed point; *description* can be conveyed through the use of action terms or analogies [150]. Some examples of using direction as an external cue includes telling an athlete to jump as close as possible to a cone just out of reach or having them jump vertically to reach a target (towards a fixed point). Description as an external cue can include a coach describing a squat pattern as “sitting on a chair” to get an athlete to reach their hips back as they descend (analogy) or telling an athlete to “punch” instead of “push” (action term), as it implies an explosive movement. Creativity of the coach is the only limiting factor in the use of external cues; however, external focus of attention can improve performance in strength and power exercises, as well as correcting technical errors.

Coaches often use a combination of verbal and video feedback to help identify and correct movement. Indeed, Rucci and Tomporowski [151] showed that a combination of verbal and video feedback provided better improvements in the hang power clean technique than video feedback only. Additionally, several studies demonstrate the effectiveness of video modelling and video feedback on weightlifting movement kinematics [152, 153]. In a group setting, highlighting a student with good technique in a given exercise (e.g. snatch) may improve confidence and act as a more relatable model than an elite level competitive athlete (e.g. Olympic weightlifter). Furthermore, research has shown that improvements in kinematic variables due to combined feedback methods result in improved kinetic variables such as force and power in the power snatch [154] and power clean [155]. Therefore, although video feedback may help a coach provide feedback, a coach must have the methodological knowledge of movement and be able to explain it to a young athlete in everyday terms.

What next?

Ideally, after a year of training, the students would continue to participate in athletic development during curriculum throughout secondary school. A new annual plan that progresses athletic development beyond the previous year should be implemented. Following the long summer holidays, coaches will likely need a general preparation phase to reinforce movements and fitness qualities mastered the previous year. More complex movements may be introduced throughout the year, as well as higher intensities and greater volume. After children have gone through their pubertal growth spurt, a focus on hypertrophy may be emphasized during certain training stages [3]. Training sessions may also become more structured as youth mature and are able to respond to more instruction. Additionally, as training and sport intensity increases, monitoring of workload and athletic performance remains an integral key to reducing injury and improving performance. For reference to a multi-year high school plan, see the review from Jeffreys [13].

Practical Applications

The annual plan presented in this manuscript provides the reader with an applied, real-world example of how strength and conditioning provision has been implemented within the physical education curriculum in a high school in New Zealand. Specifically, it has demonstrated how principles of periodization can be applied to the high school setting and highlighted how the resistance training programs can be delivered to young high school students with a limited training age. Using a classic (or linear) approach to periodization will allow for the development of multiple fitness components simultaneously, while still allowing for emphasis to shift based on the goal of each mesocycle. To truly target overall athletic development, training should initially aim to improve technical competency in a broad range of physical qualities (e.g. resistance training, linear speed, change-of-direction). However, once a robust level of competency is reached, practitioners should sensibly manipulate training in order to satisfy the principle of progressive overload. It should be noted that training intensity should never be increased at the expense of technical competency. Providing valuable feedback using external cues, even video analysis where possible, and adopting a constraint-led approach to skill development all within a motivationally-oriented climate should help students realise improvements in athleticism in a variety of contexts. Students should aim to build upon their physical training foundation in subsequent high school years, which may lead to a lifelong active and healthy lifestyle.

Chapter 4: The Influence of Maturity Offset, Strength and Movement Competency on Motor Skill Performance in Adolescent Males

This chapter comprises the following article published in *Sports*.

Reference:

> Pichardo A.W., Oliver J.L., Harrison C.B., Maulder P.S., Lloyd R.S., & Kandoi R. (2019). The influence of maturity offset, strength, and movement competency on motor skill performance in adolescent males. *Sports*, 7(168), 1-11.

Preface

Chapter 2 reviewed athletic development models created to progress training variables throughout a child's sporting journey. These models highlight the role that maturation plays in athletic development, the importance of strength development from an early age, and the development of a broad range of movement skills by engaging in a variety of activities. Furthermore, Chapter 3 provided an applied example of a school-based resistance training program that would help adolescents with a low training age develop strength and movement skill in a variety of contexts. Given the limitations of previous research, the relative contribution of maturity status, strength, and movement competency on motor skill performance of adolescent males remains unclear. Therefore, the aim of this chapter was to determine the influence of maturity offset, strength, and movement competency on motor skill performance. This information may help practitioners with talent identification and the design and implementation of athletic development programs.

Introduction

Motor skill performance during adolescence is influenced by several factors, such as maturation, strength, and movement competency [3, 14, 156], but the relative importance of each of these factors is currently unknown. Biological maturation, which refers to the process of becoming physically mature [157], is accompanied by large increases in androgenic hormones, lean body mass, stature, and neuromuscular coordination in male youth during the adolescent growth spurt [35]. In European males, this growth spurt occurs between 13-14 years old, with boys growing at a maximum rate of over nine centimeters and over eight kilograms per year [158]. Due to the natural increases in height and muscle mass experienced by males during the growth spurt, strength and performance in motor skill tasks such as running, jumping, sprinting, and throwing have shown the greatest rates of development during this period [158]. Since the onset and rate of change of these biological changes vary between youth, more physically mature boys are often selected for representative teams [159, 160] or viewed as superior to their less mature counterparts of equal chronological age. However, researchers and practitioners can mitigate this bias in a non-invasive way by using somatic measurements to predict PHV [120] and adult height [121]. Monitoring biological maturation can provide valuable information to practitioners to better assess and compare youth of a similar chronological age during a period when biological age can vary by as much as five years [157].

Muscular strength can be defined as the ability to produce force [161] and its importance for athletic performance has been noted by several other authors [63, 162, 163]. It is generally accepted that maturity status and absolute strength are strongly associated, as more mature boys outperform less mature boys during dynamic [164] and isometric strength assessments [165, 166]. This is in part due to increases in body stature and muscle mass that accompany maturation in males. Relative strength, which accounts for a person's body mass, may be a better predictor than absolute strength for motor skill tasks such as running and jumping [167, 168] since the person must propel their own body mass through space. It is unclear, however, the extent to which relative strength and maturity are independent of one another. Some authors have demonstrated that measures of relative strength are important for running speed but do not change with advancing age or maturation [169]. However, other authors have suggested that relative strength continues to increase through maturation in boys [47]. Due to the conflicting results from previous studies, further research examining the relationship between maturation and speed is warranted.

The development and reinforcement of movement competency during adolescence is especially important, as some children may experience a temporary loss in coordination during periods of rapid growth [80], a term coined "adolescent awkwardness". Movement competency refers to an individual's ability to perform a movement in an optimal manner [130] and is commonly assessed using various screening tools, such as the Resistance Training Skills Battery (RTSB) [133]. Due to the increased movement variability during this phase [170], circa-PHV children are at a heightened risk of injury [171]. Additionally, RTSB scores have been linked to push-up and standing long jump performance [172], as well as cardiorespiratory endurance in youth [173], suggesting movement competency may have both athletic performance and health related implications. However, previous studies have examined the relationship between movement skill and muscular fitness in relatively heterogeneous samples, which potentially inflates the strength of any relationships [133]. For example, Lubans et al. [133] found that RTSB scores explained 39% of the variance in muscular fitness but used both male and females and included a relatively large age range (12-16 years). Other evidence has indicated that maturity and functional movement screen scores influence jump and agility performance in pre- and post-pubertal soccer players [78], excluding circa-pubertal boys. Although useful, these findings may not accurately represent the role that movement competency has in motor skill development of circa-PHV males. Therefore, the purpose of this study was to determine the relative contribution of maturity, strength, and movement competency to motor skill performance in running, jumping, and throwing tasks.

Methods

Experimental Approach to the Problem

A cross-sectional design was used to examine the influence of maturity offset, strength, and movement competency on motor skill performance and was conducted according to the Strengthening the Reporting of Observational Studies in Epidemiology [174]. Testing took place on two non-consecutive days during an hour-long physical education class. Four classes (20-40 students each) were divided evenly into groups of five to seven participants and completed the tests in a randomized order to limit systematic bias. Day one consisted of collecting anthropometric measures, IMTP peak force, 10-, 20- and 30-meter sprint times, HJ distance and CMJ height. On the second day, movement competency was assessed using the RTSB and upper body power was measured using the seated medicine ball throw (SMBT). The Yo-yo Intermittent Recovery Test Level 1 (YYIRTL1) was performed during a separate session the following week. The IMTP and SMBT were conducted by the primary researcher, anthropometric measures were obtained by trained physical education teachers, and several graduate level research assistants conducted the sprint and jump tests. A standardized dynamic warm-up (approximately 10 minutes) consisting of 10 bodyweight squats, 10 lunges, and 10 push-ups, as well as submaximal jumps and sprints at 50, 75, and 90%, was completed prior to each testing session.

Subjects

One-hundred and eight circa-PHV males (aged 13-14 y) from a local secondary school in New Zealand volunteered to participate in this study. Descriptive statistics for all participants are shown in Table 1. No participants were injured at the time of testing and all were regularly participating in physical education classes. Parents and participants were informed of the risks and benefits of the study and gave written informed consent and assent, respectively. The project received ethical approval from the University's Ethics Committee (reference 17/11).

Table 0.1. Participant characteristics.

Characteristics	**(*n* = 108)**
Age (years)	13.9 ± 0.5
Sitting height (cm)	85.9 ± 5.2
Standing height (cm)	166.1 ± 9.4
Body mass (kg)	57.6 ± 13.9
Maturity offset (years from PHV)	0.2 ± 0.9

Values are means and standard deviations.

Procedures

Anthropometry

Standing height was measured in centimeters using a stadiometer (Model: WSHRP; Wedderburn, New Zealand). Seated height was measured in centimeters using a meter stick taped to the wall above a 40 cm wooden box. Body mass was measured in kilograms using a digital scale (Model: TI390150K; Tanita, New Zealand). These data were then incorporated into a regression equation to predict maturity offset, which is the length of time (in years) from PHV [120]: Maturity offset = -(9.236 + 0.0002708 * leg length and sitting height interaction)-(0.001663·age and leg length interaction) + (0.007216·Age and sitting height interaction) + (0.02292 * weight by height ratio). The Mirwald et al. [120] equation has a standard error of 0.57 years in males and was used because it is a non-invasive method to predict maturation status.

Isometric Mid-thigh Pull

The IMTP was performed using a fixed barbell and two portable force plates (Pasco, California, USA) sampling at a frequency of 100 Hz and variables were analyzed using custom-built LabVIEW software. The barbell was fixed in place and the distance between the bar and force plates was adjusted by adding or removing incompressible one-centimeter thick rubber mats until the barbell was positioned just below the hip crease, approximately where the second-pull of a clean starts [161]. Participants used a self-selected mid-thigh clean position with an upright torso (knee angle approximately 125-145°; hip angle approximately 140-150°) [175]. Feet were approximately hip width apart with hands just outside the legs, knees flexed, and torso upright in accordance with previous research [176]. Once the participants were stable in their self-selected positions, a countdown of "3, 2, 1, pull," was given to initiate the trial. Participants were instructed to pull as hard and as fast as possible for approximately three seconds. Verbal encouragement was given to all participants throughout the trial. Participants performed two maximal trials each with approximately one minute of passive rest between pulls [175]. The trial was discounted and repeated if a countermovement was visible or the participant did not sustain maximal effort for three seconds and the better of the two trials was used for analysis. The maximum force during the pull was reported as absolute peak force ($IMTP_{ABS}$) and was divided by body mass to determine relative peak force ($IMTP_{REL}$).

Resistance Training Skills Battery

Movement competency was assessed using the RTSB, which uses six bodyweight movements: the bodyweight squat, push-up, lunge, suspended row, standing overhead press, and front support with chest touches [133]. Each movement was performed according to the guidelines from Lubans et al. [133] except the bodyweight squat, which included the use of a wooden dowel rod for the squat portion of the assessment. This alteration was used as a more specific tool to assess readiness to back squat. Each movement was filmed from the sagittal and frontal plane with an iPad (3^{rd} and 4^{th} generation, Apple Inc., USA) mounted on a tripod set approximately one meter high and three meters from the center of the capture area. Video assessments were retrospectively played using QuickTime Player (version 10.4) and rated according to criteria from Lubans et al. [133]. The push-up and suspended row were rated according to four criteria whereas the other movements were rated according to five criteria. The participant received a “1” for each criterion met or a “0” if they failed to achieve the criteria. The best repetition was scored for each skill. The score from each skill was added together to determine the resistance training skills quotient (RTSQ), which can range from 0-56, with a higher score being better than a lower score.

Sprints

The 10 m sprint time was measured on a wooden gymnasium floor surface using a wired dual-beam infrared system (Swift Performance, Australia). Participants also completed a 30 m sprint outside on an artificial turf surface to determine 20 and 30 m sprint times using a wireless dual-beam infrared system (SpeedLight; Swift Performance, Australia). These tests were conducted separately to mitigate any weather effects on the 10 m sprint. The environmental conditions were the same for all participants when performing the outdoor 30 m sprint (sunny, no heavy wind). Participants used a stationary start 50 cm behind the first timing gate for all sprints. Each participant performed two trials of the 10 and 30 m sprint with at least two minutes rest between trials and the best times were used for analysis. Participants used the same footwear for each testing session.

Horizontal Jump

Participants performed a bilateral HJ with their hands on hips to minimize the effect of arm swing [177, 178]. The trial was discounted if the participant’s hands moved from the hips or the feet moved upon landing and therefore, another trial was allowed. Jump distance was measured to the nearest centimeter from the furthest back heel using a tape measure secured to the floor. Each participant performed two successful repetitions with at least one-minute rest.

Countermovement Jump

The CMJ was performed using a linear position transducer (GymAware; Kinetic Performance Technology, Canberra, Australia) attached to a wooden dowel rod placed across the shoulders in a back-squat position. The subject was instructed to squat down to a self-selected depth and jump as high as possible. Each participant performed two repetitions with at least 30 seconds rest and the highest jump was used for analysis [179]. The jump height was recorded in centimeters using the GymAware Lite app (version 2.10) on an iPad (3rd generation; Apple, Inc., USA).

Seated Medicine Ball Throw

The SMBT was used to assess upper body power and was measured to the nearest centimeter using a tape measure placed against the wall and taped to the wooden floor of an indoor gymnasium. Participants were instructed to sit with their legs straight and back flat against the wall and hold a four kilogram rubber medicine ball at chest level until instructed to throw. A pause at the chest was used to minimize any momentum or stretch-shortening cycle effects of using a dynamic start. When instructed, the subject threw the ball as far as possible with their back staying in contact with the wall. Each participant performed two throws with at least 30 seconds rest between throws. The distance was measured from the wall to where the middle of the ball landed, and the best throw was used for analysis.

Yo-yo Intermittent Recovery Test Level 1

The YYIRTL1 was performed in a gymnasium according to the procedures used by Krustrup et al. [180]. The test involved two, 20-meter runs back and forth at an increasing speed according to an audio recording playing throughout the gym. Each stage was separated by 10 seconds of active rest consisting of the participants walking five meters, touching a wall, and walking back to the starting line before the next beep. The participant was eliminated when he failed to reach the finish line twice and the total distance covered was recorded and used for analysis. Distance covered in the YYIRTL1 was highly reliable between-sessions in a group of under-15 males, with a coefficient of variation (CV) below 8% and an intraclass correlation coefficient (ICC) of 0.92 [181].

Statistical Analysis

Descriptive data are presented as mean values and standard deviations (*SD*). A Kolmogrov-Smirnov test confirmed that all variables were normally distributed. Pearson's product-moment correlation coefficient (*r*) was used to determine relationships between maturity offset, strength, movement competency, and each performance variable. The correlation coefficients were classified according to Hopkins [182]: 0.0-0.1 = trivial, 0.1-0.3 = small, 0.3-0.5 = moderate, 0.5-0.7 = large, 0.7-0.9 = very large, 0.9-1 = nearly perfect. A stepwise linear regression analysis was used to determine the predictors for the dependent performance variables. The independent variables included maturity offset, $IMTP_{ABS}$, $IMTP_{REL}$, and RTSQ, whereas the dependent variables included the 10, 20, and 30 m sprint time, HJ, CMJ, SMBT, and YYIRL1 for each regression model. To further examine the influence of relative strength on movement competency, an odds ratio (OR) was calculated using binary logistic regression, with participants classified as lower or higher competency based on achieving a RTSQ below or above the group mean. The $IMTP_{REL}$ results were converted to z-scores and participants classified as either low (z > -1.0), average (z = -1 to 1), or high (z > 1) strength. Within-session reliability was calculated using pairwise comparisons on log-transformed data to reduce the effects of any non-uniformity of error [183]. The typical error was expressed as a coefficient of variation (CV) to determine absolute reliability and the intraclass correlation coefficient (ICC) was used to determine relative reliability. All descriptive and reliability data were analyzed using Microsoft Excel 2016, whereas Pearson correlations, regression analyses, and OR were conducted using SPSS (version 25; SPSS Inc, Chicago, IL) with statistical significance set at $p \leq 0.05$.

Results

All tests achieved acceptable (ICC ≥ 0.70 and CV ≤ 15.0%) [170] within-session reliability: IMTP = ICC of 0.93 and CV of 8.3%; 10-m sprint = ICC of 0.93 and CV of 2.1%; 20-m sprint = ICC of 0.97 and CV of 1.5%; 30-m sprint = ICC of 0.97 and CV of 1.5%; HJ = ICC of 0.90 and CV of 4.6%; CMJ = ICC of 0.74 and CV of 13.5%; SMBT = ICC of 0.90 and CV of 6.3%. The RTSB achieved acceptable intra-rater reliability with an ICC of 0.96 and CV of 6.1% after 10 participants were rated and rerated seven days later. Descriptive results for the performance variables of the group are shown in Table 2. The relationships between maturity offset, strength, movement competency, and the motor skill performance variables are shown in Table 3. Maturity offset had a significant, large relationship with $IMTP_{ABS}$ (r = 0.69, p < 0.01), significant, small to moderate relationships with sprint, jump and throw measures (r = 0.23-34, p < 0.05), and non-significant, trivial relationships with $IMTP_{REL}$, RTSQ and YYIRTL1 (r = 0.00-0.09, p > 0.05). The $IMTP_{ABS}$ had significant, large to very large correlations with $IMTP_{REL}$, 30 m sprint, HJ and SMBT ($r = 0.50$-0.82, $p < 0.01$) and moderate correlations with 10- and 20-meter sprint, CMJ, and YYIRTL1 ($r = 0.27$-0.49, $p < 0.01$). The $IMTP_{REL}$ had significant, small to large relationships with all performance variables ($r = 0.27$-0.61, $p < 0.01$) and in general had larger correlations with performance variables than $IMTP_{ABS}$. The RTSQ had significant, small to moderate relationships with $IMTP_{REL}$ and running measures only ($r = 0.21$-0.37, $p < 0.05$).

Table 0.2. Descriptive characteristics of strength and motor performance variables.

$IMTP_{ABS}$ (N)	924.9 ± 260.2
$IMTP_{REL}$ (N/kg)	16.2 ± 3.3
RTSQ	33.6 ± 7.2
10 m sprint (s)	1.96 ± 0.15
20 m sprint (s)	3.39 ± 0.26[a]
30 m sprint (s)	4.82 ± 0.42[a]
HJ (m)	1.55 ± 0.21
CMJ (cm)	35.9 ± 7.7
SMBT (m)	3.52 ± 0.67
YYIRTL1 (m)	759 ± 438

Values are means and standard deviations; $IMTP_{ABS}$ = absolute peak force of isometric mid-thigh pull; $IMTP_{REL}$ = relative peak force of isometric mid-thigh pull; RTSQ = resistance training skills quotient; HJ = horizontal jump; YYIRTL1 = Yo-yo Intermittent Recovery Test Level 1; CMJ = countermovement jump; SMBT = seated medicine ball throw; [a] = 69 participants.

Table 0.3. Pearson correlations between maturity offset, strength, and RTSQ and motor performance variables.

	Maturity offset	$IMTP_{ABS}$	$IMTP_{REL}$	RTSQ
$IMTP_{ABS}$	0.69**			
$IMTP_{REL}$	0.03	0.58**		
RTSQ	0.00	0.18	0.27**	
10 meter sprint	-0.29**	-0.45**	-0.60**	-0.21*
20 meter sprint	-0.31*	-0.49**	-0.61**	-0.37**
30 meter sprint	-0.33**	-0.50**	-0.59**	-0.37**
HJ	0.34**	0.50**	0.44**	0.09
CMJ	0.23*	0.37**	0.39**	0.11
YYIRTL1	0.09	0.27**	0.48**	0.28*
SMBT	0.32**	0.82**	0.28**	0.12

$IMTP_{ABS}$ = absolute peak force of isometric mid-thigh pull; $IMTP_{REL}$ = relative peak force of isometric mid-thigh pull (N/kg); RTSQ = resistance training skill quotient; HJ = horizontal jump; CMJ = countermovement jump; YYIRTL1 = Yo-yo Intermittent Recovery Test Level 1; SMBT = seated medicine ball throw; *$p < 0.05$; **$p < 0.01$.

Results of the stepwise linear regression analysis are shown in Table 4.4. The RTSQ did not significantly contribute to any of the regression models. Maturity offset, $IMTP_{ABS}$, and $IMTP_{REL}$ explained a reasonable amount of the variance for the sprints and SMBT (46-76%), whereas $IMTP_{REL}$ and maturity offset explained less of the CMJ variance (21%). Strength measures were the only predictors for HJ ($IMTP_{ABS}$ and $IMTP_{REL}$ = 27%) and YYIRTL1 performance ($IMTP_{REL}$ = 26%).

Table 0.4. Stepwise linear regression analysis of predictors of motor performance.

Dependent variable	Predictive variable(s)	R^2	Adjusted R^2
10 meter sprint	a) $IMTP_{REL}$	0.40	0.40
	b) $IMTP_{REL}$, maturity offset	0.47	0.46
	c) $IMTP_{REL}$, maturity offset, $IMTP_{ABS}$	**0.51**	**0.49**
20 meter sprint	a) $IMTP_{REL}$	0.40	0.39
	b) $IMTP_{REL}$, maturity offset	**0.48**	**0.47**
30 meter sprint	a) $IMTP_{REL}$	0.38	0.37
	b) $IMTP_{REL}$, maturity offset	**0.48**	**0.46**
HJ	a) $IMTP_{ABS}$	0.24	0.23
	b) $IMTP_{ABS}$, $IMTP_{REL}$	**0.28**	**0.27**
CMJ	a) $IMTP_{REL}$	0.17	0.16
	b) $IMTP_{REL}$, maturity offset	**0.23**	**0.21**
YYIRTL1	**a) $IMTP_{REL}$**	**0.26**	**0.26**
SMBT	a) $IMTP_{ABS}$	0.69	0.68
	b) $IMTP_{ABS}$, $IMTP_{REL}$	0.76	0.75
	c) $IMTP_{ABS}$, $IMTP_{REL}$, maturity offset	**0.77**	**0.76**

$IMTP_{ABS}$ = absolute peak force of isometric mid-thigh pull, $IMTP_{REL}$ = relative peak force of isometric mid-thigh pull; HJ = horizontal jump, CMJ = countermovement jump; YYIRTL1 = Yoyo Intermittent Recovery Test Level 1; SMBT = seated medicine ball throw; all $p < 0.001$. The bold font represents the combination of variables that explains the greatest amount of variance for each performance variable.

When compared to high strength boys, the low strength boys were nearly eight times more likely to be classified as lower competency (OR = 7.80, 95% confidence intervals (CI) = 1.48-41.21, $p < 0.05$). Although only approaching statistical significance, the average strength boys were nearly four times more likely to be classified as lower competency (OR = 3.86, 0.95-15.59, $p = 0.058$). There was a non-significant increased risk of a low strength boy being classified as lower competency when compared to an average strength boy (OR = 2.02, CI = 0.64-6.35, $p > 0.05$).

Discussion

This study examined the influence of maturity offset, strength and movement competency on motor skill performance in a group of 13-14-year-old males. The main finding suggests that strength is a greater influence than maturity or movement competency on motor skill performance of adolescent boys. Specifically, relative strength generally explains a greater percentage of motor skill performance than absolute strength. Furthermore, strength influences performance more than maturity offset, whereas maturity offset influences performance more than movement competency.

The influence of maturity offset on strength and motor skill performance was apparent in the current study as evidenced by the significant strong correlations with absolute strength, small to moderate correlations with sprint and jump, and moderate correlations with throw performance. These relationships are similar to previous research on youth males, which have shown significant relationships between maturity and absolute strength [165], speed [166, 184-186] and jump performance [159, 185]. The strength of correlations between maturity offset and a given motor skill may be partially attributed to the increase in body size during PHV. For example, the increase in muscle mass may explain the stronger correlations with $IMTP_{ABS}$ compared to CMJ height. Further, the natural increase in stature and muscle mass during the growth spurt may contribute to increased stride length and therefore faster sprint times, yet may be less beneficial for endurance tasks such as the YYIRTL1. This is reflected by the significant small to moderate correlations between maturity offset and the 10-30 m sprints, yet non-significant trivial correlation between maturity offset and the YYIRTL1. Given these findings, maturation may influence speed and endurance performance to different extents. Therefore, practitioners working with youth should understand the extent that maturity offset influences a given fitness quality when identifying talent and designing training programs.

Interestingly, maturity offset was related to $IMTP_{ABS}$ but not $IMTP_{REL}$, suggesting that relative strength measures may be a more useful tool for performance assessment in 13-14-year-old boys, as they do not appear to be influenced by maturation. Although maturity offset was not the primary predictor for any of the motor skill tasks, it contributed to predicting sprint, CMJ, and SMBT performance (22-78%). This suggests that maturation influences performance during adolescence, but not to the extent that strength does. Therefore, measuring variables that account for body mass may be a more effective method to eliminate the maturation bias during common field tests. Furthermore, practitioners should understand the influence maturation can have on motor skill performance when using field tests as selection criteria or for talent identification purposes.

The results from the current study suggest relative strength is the greatest predictor of motor skill performance and displays larger correlations than maturity offset, $IMTP_{ABS}$, or RTSQ with most measures of motor skill performance. These findings support recent research from Meyers et al. [169] which found that greater relative force is associated with step length (r = 0.79) and faster sprint speed (r = 0.42) in youth males. Furthermore, Thomas et al. [77] showed that relatively stronger athletes outperformed weaker athletes on sprint and jump performance, likely due to the ability to produce more force. Cumulatively, the current study supports findings from existing evidence in confirming the importance of relative strength on motor skill performance. Importantly, the small relationship between RTSQ and $IMTP_{REL}$ was significant, whereas the small relationship with $IMTP_{ABS}$ was non-significant, which suggests the ability to move one's own body through space is more important than overall force production. The $IMTP_{ABS}$ had the strongest correlation with SMBT performance and explained the most variance, likely due to the same absolute load used for all participants (four kg medicine ball). Despite the relationship between maturity and absolute strength, previous studies indicate measures of relative strength do not improve with increasing chronological age groups in boys [169] or girls [166], or maturity status of girls [187]. Therefore, our findings suggest that developing strength relative to body mass should be a primary goal of LTAD programs, as supported by previous reviews [3, 156] and position statements [49]. Physical education teachers can use game-based activities such as tug-of-war, obstacle courses, or partner-based exercises to help develop strength in a fun and engaging manner.

The significant small to moderate correlations between RTSQ and $IMTP_{REL}$, sprint, and YYIRTL1 indicate that movement competency is related to measures of relative strength expression, as well as more complex tasks such as sprinting and running. This finding agrees with previous literature that showed associations between measures of movement skill and muscular fitness [79, 133, 172]. However, there were no significant relationships between RTQS and jump measures in the current study, which may be due to the nature of the assessments. Specifically, jumping performance was assessed bilaterally one repetition at a time, whereas the sprint and YYIRTL1 tests required coordination of contralateral limbs for many rapid, consecutive actions. Thus, moving competently may have a greater influence on performance of complex movements, such as sprinting or sport-specific skills and have less influence on relatively simple tasks, such as a single CMJ or HJ. Furthermore, although correlations between relative strength and competency were only moderate, odds ratio suggests that strength has an important role to play in supporting movement competency. Low and average strength boys were nearly eight and four times more likely to be classified as lower competency, respectively, than high strength boys. This finding highlights the relationship between strength and movement competency and therefore the need for resistance training in adolescence. Nonetheless, motor skill performance is primarily influenced by factors other than movement competency, such as strength and maturity.

A limitation of the current study is that it only included male participants. While males typically experience a neuromuscular spurt from pre- to post puberty, females typically do not and therefore have an increase in knee valgus [188] and landing force, as well as a decrease in jump performance [189]. Given the higher risk of lower-extremity injury in females [188], future research should investigate the relationship between strength and motor skill performance in females. Similarly, future research should aim to investigate the influence of strength on injury risk factors, such as landing kinematics, in adolescent athletes. This information may assist practitioners in developing training programs aimed to reduce the risk of injury in adolescent athletes.

Conclusions

In conclusion, the current study showed that relative strength is an important factor in differentiating sprint and jump performance in 13-14-year-old boys. Maturity further contributes to performance, but the extent is task dependent and should be accounted for using relative measures aimed to reduce the influence of body size. The RTSQ was not shown to be a significant predictor of performance in the regression analyses but had significant relationships with running performance. Although relative strength and movement competency do not necessarily naturally improve, previous research has demonstrated the long-term trainability of these physical qualities [47, 190, 191]. Thus, it is recommended that while youth should be encouraged to train all components of fitness for optimal development [3], a large emphasis should be placed on developing levels of relative strength and movement skill, particularly around PHV. Future research should examine how different training methods improve relative strength, movement competency, and motor skill performance of adolescent males.

Chapter 5: Effects of Combined Resistance Training and Weightlifting on Motor Skill Performance of Adolescent Male Athletes

This chapter comprises the following article published ahead of print in the *Journal of Strength and Conditioning Research*.

Reference:

Pichardo A.W., Oliver J.L., Harrison C.B., Maulder P.S., Lloyd R.S., & Kandoi R. (2019). Effects of combined resistance training and weightlifting on motor skill performance of adolescent male athletes. *Journal of Strength and Conditioning Research*. Published ahead of print.

Preface

Chapter 4 used a cross-sectional approach to examine the influence of maturity offset, strength, and movement competency on motor skill performance. Muscular strength, particularly relative strength, was found to be the strongest predictor of performance. Additionally, the RTSQ was significantly related to sprint and endurance performance, albeit a small relationship. Traditional strength, plyometric, and weightlifting training are methods often used to improve athletic performance. Specifically, weightlifting training may provide greater benefit than combined training alone, due to the complexity and velocity inherent in snatch and clean & jerk variations. Thus, Chapter 5 aims to compare the effects of resistance training with and without weightlifting movements on motor skill performance. The training program presented in this chapter is based upon the principles from Chapter 2 and is similar to the generic program provided in Chapter 3.

Introduction

Resistance training is becoming a widely accepted training method to promote successful LTAD. Common forms of resistance training such as traditional strength training, plyometric training, weightlifting and a combination of these have been shown to be safe and effective when performed under proper supervision, and subsequently, are endorsed by several organizations' position statements [14, 49, 52]. A recurring theme surrounding successful LTAD includes proper progression of training structure, exercises and intensity taking into account technical competency and biological age [14]. Evidence indicates that a longer training period (> 23 weeks) and higher exercise intensity (+80% 1RM) are most effective in improving strength in young athletes [11] and are appropriate for boys and girls that display high levels of motor competency. Specifically, a series of studies on youth soccer players and weightlifters following a two-year traditional strength training program adhering to these guidelines showed large gains in relative and absolute squat strength [47], sprint [47] and COD performance [48]. Despite the evidence regarding the efficacy of consistent training at the appropriate intensity, different resistance training programs have not been compared over a longer period.

Training adaptations in youth are generally specific to the type of training performed. For example, meta-analytical data show that power training improves jump performance more than strength training, but the latter is more effective in eliciting gains in strength [54]. However, the broader goal of LTAD programs is to promote the improvement of multiple physical qualities. Specifically, evidence suggests a combined approach that includes traditional strength training and plyometric training is most effective for improving various motor skill outcomes [18, 192].

Weightlifting training, which refers to highly technical, explosive multi-joint exercises such as the snatch, clean and jerk, and their derivatives [5], provides a more specialized form of resistance training. However, there is limited research that has examined how combining this mode of training with more traditional resistance training influences LTAD. Research suggests that the derivatives of the full lifts can serve as a valuable teaching progression that also provides a similar training stimulus to the full movements [21, 193]. One study on young weightlifters (aged 10-15 years) showed absolute and relative snatch and clean and jerk strength nearly doubled over extended training periods (28.8 ± 4.4 months), demonstrating the safety and trainability of weightlifting movements when performed under qualified supervision [21]. Training with these movements has been shown to improve jump [20] and sprint [19] performance compared to traditional strength training after eight and 12 weeks in post- and pre-peak height-velocity males, respectively. Peak height velocity refers to the maximal velocity of growth in height, and typically occurs between age 13.8-14.2 in European males [157]. Due to the paucity of long-term research examining motor skill development, it is important to determine how motor skill development might be disrupted, or even improved, using different types of training during periods of maximal growth in height. Therefore, the purpose of this study was to determine the effects of different long-term training programs that combine different forms of resistance training with or without weightlifting on motor skill performance in adolescent male athletes.

Methods

Experimental Approach to the Problem

A cluster randomized trial was used to determine the effects of a CRT or CRT&WL approach on motor skill performance in young males (age 12-14) over an academic year (11 months). Boys enrolled in an athlete development program at their school were matched by maturation, then divided into one of two training groups: CRT or CRT&WL training. The CRT undertook a combination of strength and plyometric training, whereas the CRT&WL group also completed strength and plyometric training but replaced some of the strength exercises with weightlifting exercises. The groups performed their training program twice weekly throughout the academic year. Once testing weeks and school holidays were accounted for, this allowed for 28 weeks of training, as shown in Figure 5.1. All participants were tested pre-, mid- (14 training weeks) and post-training (28 training weeks) for the following dependent variables: RTSQ, $IMTP_{ABS}$, $IMTP_{REL}$, CMJ, HJ, SMBT,10 m sprint, 20 m sprint, and 30 m sprint.

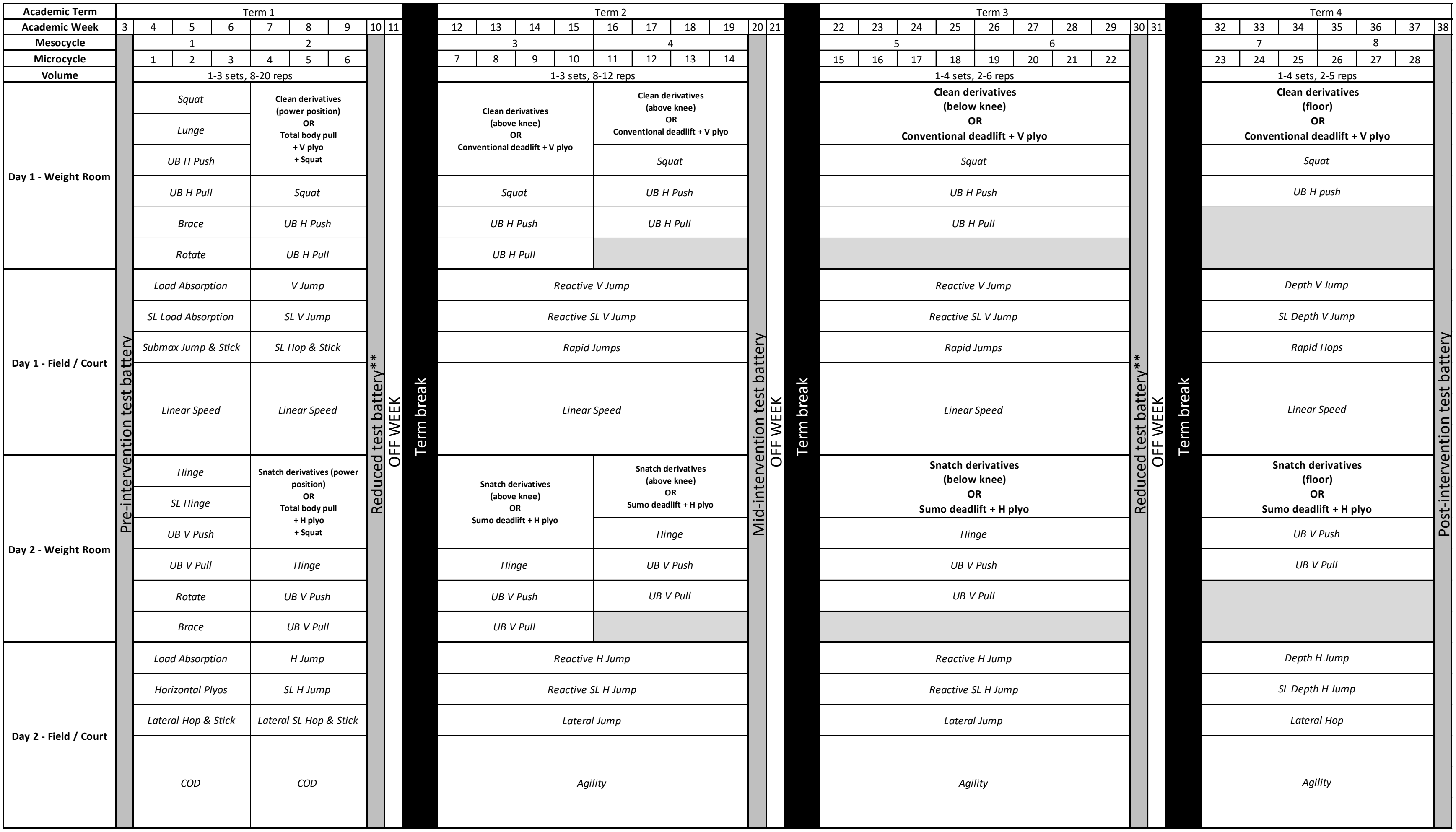

Figure 0.1. Annual plan for combined resistance training and combined resistance training & weightlifting groups. The exercises in bold represent the differences between the groups while all italicized exercises represent exercises common to both groups. In the da daily plans, each row represents an exercise slot, so taller blocks indicate multiple exercises used for a given movement. UB = upper body; SL = single leg; H = horizontal; V = vertical; COD = change of direction; ** = reduced test battery that was not included in analysis.

Subjects

Seventy-three male secondary school students (years nine and ten) aged between 12 and 14 years were recruited to participate in this study. To be included in the final analyses, participants were required to complete at least 70% of the training sessions. Fourteen subjects did not meet this criterion, and therefore, 59 subjects were included in the analyses. The participants were recruited from their school's athlete development program, and each class was matched by maturity offset then assigned to a CRT (n = 28) or CRT&WL training (n = 31) group. There were no significant between-group differences at baseline for any of the performance variables ($p > 0.05$). The year ten students (equal to ninth grade in the United States school system), which made up approximately half of each training group, had participated in the program the previous year, whereas the year nine students (equal to eighth grade in the United States school system) which made up the other half of each training group were new to the program. However, resistance training was not included in the program the previous year, so all the participants had a resistance training age of less than one year. Subject physical characteristics are shown in Table 5.1. Both groups performed the training program and their habitual physical education curriculum, which included two or three, one-hour long sessions per week inclusive of physical activities. All participants and parents or guardians were informed about the testing procedures and provided written informed assent and consent. The study was reviewed and approved by the Auckland University of Technology institutional research ethics committee.

Table 0.1. Subject physical characteristics (mean ± SD).

	Combined Resistance Training (n = 28)			Combined Resistance Training & Weightlifting (n = 31)		
Age (years)	13.9 ± 0.6			14.0 ± 0.5		
Maturity offset (years from PHV)	0.1 ± 0.9			0.3 ± 0.6		
	Pre	Mid	Post	Pre	Mid	Post
Height (cm)	165.2 ± 10.11	167.9 ± 10.1	170.2 ± 10.1	167.6 ± 8.1	172.4 ± 7.9	173.4 ± 8.4
Body mass (kg)	56.4 ± 13.1	59.1 ± 13.4	61.4 ± 13.3	56.7 ± 10.9	60.0 ± 11.7	64.2 ± 12.1

PHV = peak height velocity

Procedures

During each testing week, sessions took place during an hour-long secondary school lesson on two non-consecutive days. Session one consisted of collecting anthropometric measures, the IMTP, HJ distance, CMJ height and sprint measures and session two consisted of the RTSB and SMBT. The mid- and post-testing sessions were performed during the same lesson on the same day of the week and at the same time of day as the pre-testing session. Prior to testing each session, a standardized dynamic warm-up consisting of bodyweight exercises and submaximal jumping and running was completed by all participants. After the warm-up, participants completed each test in a randomized order which was held constant for each subsequent testing session. Participants performed two trials of each test and the best trial was used for analysis.

Resistance Training Skills Battery

The RTSB provides an assessment of basic resistance training skill competency using six movements: the bodyweight squat, push-up, lunge, suspended row, standing overhead press, and front support with chest touches [133]. Each movement was performed according to the guidelines from Lubans et al. [133] except the bodyweight squat, which was performed using a back squat assessment protocol from Myer et al. [134]. This protocol included a wooden dowel across the back which aids upper back engagement and prepares athletes for back squatting with external loads, which is more specific to the aims of the intervention. Each movement was filmed from the sagittal and frontal plane with an iPad (3rd and 4th generation, Apple Inc., USA) mounted on a tripod set approximately one m high and three m from the center of the capture area. Video assessments were retrospectively played using QuickTime Player (version 10.4) and rated according to criteria from Lubans et al. [133] to determine a RTSQ, where a higher score is favorable to a lower score. Test-retest reliability of the RTSB has been shown to effectively rank youth's RTSQ (ICC = 0.88), while construct validity demonstrated a significant relationship between RTSQ and muscular fitness, making it a valuable screening tool for overall motor skill performance.

Isometric Mid-thigh Pull

The IMTP was performed using two portable force plates (Pasco, California, USA) sampling at 100 Hz and variables were analyzed using custom software. A barbell was fixed in place and the distance between the bar and force plates was adjusted by raising each plate on dense, incompressible one cm thick rubber mats until the barbell was positioned just below the hip crease, approximately where the second-pull of a clean starts. Subjects used a self-selected mid-thigh clean position (knee angle approximately 125-135°). Feet were approximately shoulder width apart with hands just outside the legs, knees flexed, and torso upright in accordance with previous research [176]. Once stable in their self-selected position, participants were instructed to pull as hard and as fast as possible for approximately three seconds. Verbal encouragement was given to all subjects throughout the pull. $IMTP_{ABS}$ refers to the highest force obtained during the pull and was divided by body mass to obtain $IMTP_{REL}$. Each participant performed two maximal trials with approximately one-minute rest and the best trial was used for analysis. Within-session and between-session reliability of peak force of the IMTP using this protocol was found to be high in youth males (within-session ICC: 0.97-0.98, CV: 4.1-4.3%; between-session ICC: 0.96, CV: 4.6%) [194].

Countermovement Jump

The CMJ was performed using a linear position transducer (GymAware; Kinetic Performance Technology, Canberra, Australia) attached to a wooden dowel rod placed across the shoulders in a back-squat position. The subject was instructed to squat down to a self-selected depth and jump as high as possible. The jump height was recorded using the GymAware Lite app (version 2.10) on an iPad (3rd generation; Apple, Inc., USA). Each subject performed two jumps with approximately one-minute rest and the best jump was used for analysis. Previous studies have shown high reliability in CMJ height using linear position transducers [195, 196].

Horizontal Jump

Subjects performed the HJ with their hands on hips to minimize the effect of arm swing [177, 178]. The trial was discounted if the participant’s hands moved from the hips or the feet moved upon landing and another trial was allowed. Jump distance was measured to the nearest cm from the furthest back heel using a tape measure taped to the floor. Each participant performed two jumps with about one-minute rest and the best jump was used for analysis. Previous research has shown HJ distance in youth to have a CV of < 10% and ICC > 0.80 in pre-, mid- and post-peak height-velocity youth [170].

Sprints

The 10 m sprint time was measured in an indoor gymnasium using a wired dual-beam infrared system (Swift Performance, Australia). Acceleration was measured over 10 m with a stationary start 50 cm behind the first timing gate. Each participant completed two trials each and the best performance was used for analysis. A 30 m sprint, with 20 m and 30 m split times, was measured outside on an artificial turf surface using a wireless dual-beam infrared system (SpeedLight; Swift Performance, Australia). Subjects used a stationary start 50 cm behind the first timing gate. Each participant performed two 30 m sprints with approximately one-minute rest and the best 20 m and 30 m splits were used for analysis. Participants used the same footwear for each testing session.

Seated Medicine Ball Throw

The SMBT was used to assess upper body power and was measured to the nearest cm using a tape measure placed against the wall and taped to the wooden floor of an indoor gymnasium. Subjects were instructed to sit with their legs straight and back flat against the wall and hold a four kg rubber medicine ball at chest level until instructed to throw. A pause at the chest was used to minimize any momentum or stretch-shortening cycle effects of using a dynamic start. When instructed, the subject threw the ball as far as possible with their back staying in contact with the wall. The distance was measured from the wall to where the middle of the ball landed. Each participant performed two throws with about 30 seconds rest and the best throw was used for analysis. Acceptable within- (r = 0.93-0.94) and between-session (r = 0.88) reliability has been shown for SMBT distance in youth [197].

Training Program

Training took place twice per week on nonconsecutive days for 28 weeks of training in total. Due to the four-term New Zealand academic schedule, training was divided into four training periods lasting six-weeks, eight-weeks, eight-weeks and six-weeks separated by two-week holidays between terms, as shown in Figure 5.1. Each six- or eight-week training block was then divided into two mesocycles lasting three or four weeks, respectively. Both groups split each session between training in the weight room and a field or court, alternating which type of training was performed first. Each group completed the same three-week introductory mesocycle using bodyweight exercises only. After the first mesocycle, both training groups completed the same field-based exercises but followed slightly different resistance training programs. The training programs were identical in sets and repetitions, but exercise selection differed between the CRT and CRT&WL groups, as shown in Figure 5.1. Each participant completed either two or three weightlifting movements or similar traditional strength training exercises depending on group, followed by two or three key exercises common to both groups, such as the back squat. The weightlifting movements followed a top-down approach as suggested by previous literature, starting from the mid-thigh, or power, position [5, 21]. Volume increased from one to three sets of five to 12 repetitions in the first six-week term, to two to five sets of two to four repetitions in the last six-week term. Each exercise was progressed across three variations based on exercise complexity and external load, similar to Meylan et al.'s study using a similar cohort [128]. Athletes started each term with the least complex exercise variation and progressed complexity and external load with the guidance of the practitioners. Participants also recorded the load used for each set in a training log, which helped to ensure they were progressively overloading each exercise. Feedback to ensure technical competency and motivation were given throughout the intervention. Each training session was supervised by the primary researcher who was a certified strength and conditioning specialist and held a Sport Performance Coach certification with USA Weightlifting. A physical education teacher and an exercise science graduate assistant were also present throughout the study period. A reduced test battery was completed at the end of term one and three but did not include all the tests that the pre-, mid- and post-test sessions did and therefore were not included in the analysis.

Statistical Analysis

A 2 × 3 repeated-measures analysis of variance (ANOVA) was performed on the absolute values of height, body mass and maturity offset, as well as the absolute values of nine performance variables to determine the main effects between group (CRT vs CRT&WL) and time (pre, mid, post). Sphericity was assessed using Mauchly's Test and the Greenhouse-Geisser adjustment was applied where this was violated. A Bonferroni post hoc test was used to identify pairwise differences. Effect size calculations on absolute values were performed using Cohen's *d* both for within-group changes and to examine any effects in the CRT&WL group over and above effects of the CRT group. In the latter, effect sizes were calculated by the change in mean of the variables (post-test minus pre-test values) in the CRT&WL group minus the change in the mean in the CRT group, divided by the pooled SD of both groups. Effect sizes were interpreted according to Hopkins et al. [198] as follows: < 0.20 trivial; ≥ 0.20 and < 0.60 small; ≥ 0.60 and < 1.2 moderate; ≥ 1.20 and < 2.0 large; ≥ 2.0 and < 4.0 very large. Effect sizes and percentage change were calculated in Microsoft Excel (version 16), whereas the repeated measures ANOVA and tests of sphericity were calculated using Statistical Package for Social Sciences (SPSS Statistics, version 25). Statistical significance was set at alpha level $p \leq 0.05$ for all tests.

Results

Repeated-measures ANOVA indicated there was a significant time effect for height, mass or maturity ($F_{(2,86)} \geq 64.417$, $p \leq 0.001$) but no significant interaction effects between group and time ($F_{(2,86)} \leq 1.805$, $p > 0.05$). Post hoc analysis confirmed there were no between-group differences in these variables at pre, mid or post time points (all $p > 0.05$). These findings confirm the homogeneity of participants across both groups and time points. When growth rates across the total intervention period were converted to annual growth rates, height increased by 6.4 ± 2.9 cm/year for the CRT group and 6.0 ± 2.8 cm/year for the CRT&WL group, while body mass increased by 6.2 ± 4.2 kg/year and 7.2 ± 3.4 kg/year, respectively. The average training adherence rates were 84.3 ± 0.1% for the CRT group and 85.2 ± 0.1% for the CRT&WL group.

There were significant main effects of time for all dependent variables ($F_{(2,86)} \geq 7.628$, $p \leq 0.001$), but no significant interactions between group and time ($F_{(2,86)} \leq 1.976$, $p \leq 0.001$). Post hoc analysis revealed significant within-group effects between at least two time points for all variables ($p < 0.05$) except RTSQ for the CRT group, as shown in Figures 5.2, 5.3 and 5.4. However, the time course of change differed between variables. RTSQ significantly improved pre to mid and pre to post in the CRT&WL group only ($p < 0.05$). The $IMTP_{ABS}$ significantly improved pre to mid and pre to post in both groups ($p < 0.001$), but only mid to post in the CRT group ($p < 0.05$), whereas $IMTP_{REL}$ significantly improved pre to mid in both groups ($p < 0.01$), but only pre to post in the CRT group ($p < 0.001$) (Figure 5.2). Jump and throw measures only increased significantly from mid to post and pre to post in both groups ($p < 0.05$) (Figure 5.3). Both groups significantly improved 10, 20 and 30 m sprint performance from mid to post and pre to post ($p < 0.01$), but only the CRT group significantly improved 20 and 30 m sprint performance from pre to mid ($p < 0.05$) (Figure 5.4).

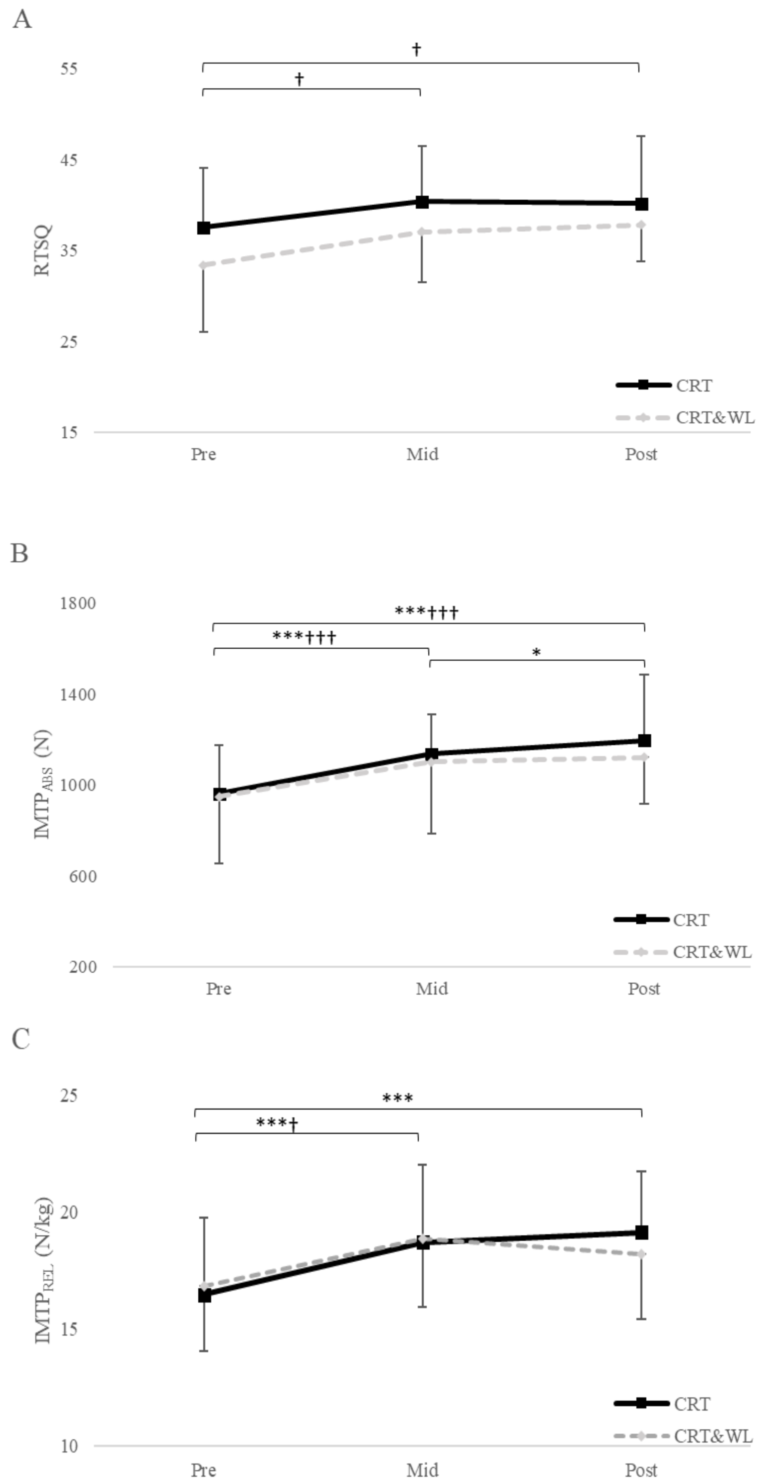

Figure 0.2. A) RTSQ = resistance training skills quotient; B) $IMTP_{ABS}$ = absolute peak force of isometric mid-thigh pull; C) $IMTP_{REL}$ = ratio scaled peak force of isometric mid-thigh pull; CRT = combined resistance training; CRT&WL = combined resistance training & weightlifting; * significant within-group difference between time points for CRT group ($p < 0.05$), ** ($p < 0.01$), *** ($p \leq 0.001$); † significant within-group difference between times points for CRT&WL group ($p < 0.05$), †† ($p < 0.01$), ††† ($p \leq 0.001$); error bars represent standard deviation.

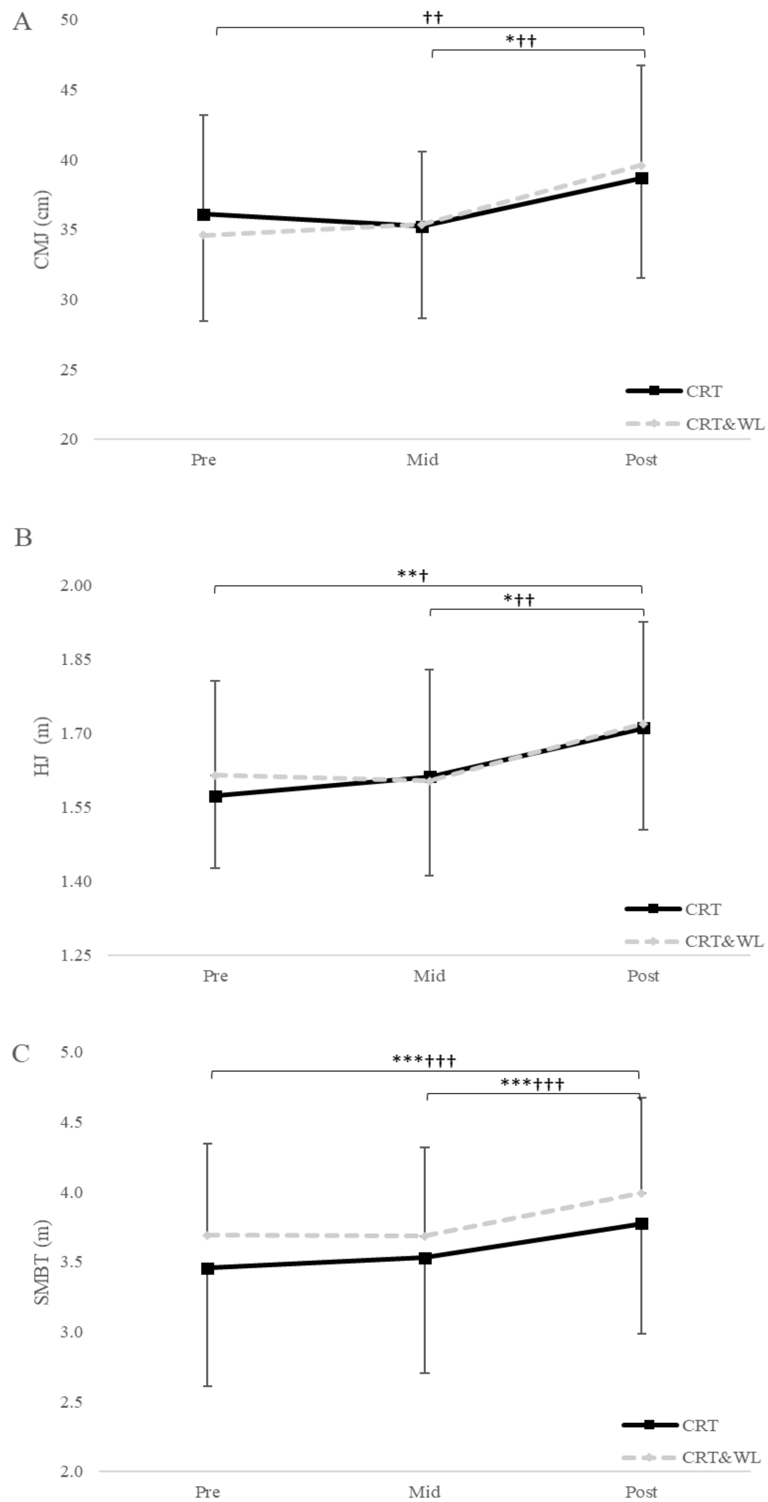

Figure 0.3. A) CMJ = countermovement jump; B) HJ = horizontal jump; C) SMBT = seated medicine ball throw; CRT = combined resistance training; CRT&WL = combined resistance training & weightlifting; * significant within-group difference between time points CRT group ($p < 0.05$), ** ($p < 0.01$), *** ($p \leq 0.001$); † significant within-group difference between times points for CRT&WL group ($p < 0.05$), †† ($p < 0.01$), ††† ($p \leq 0.001$); error bars represent standard deviation.

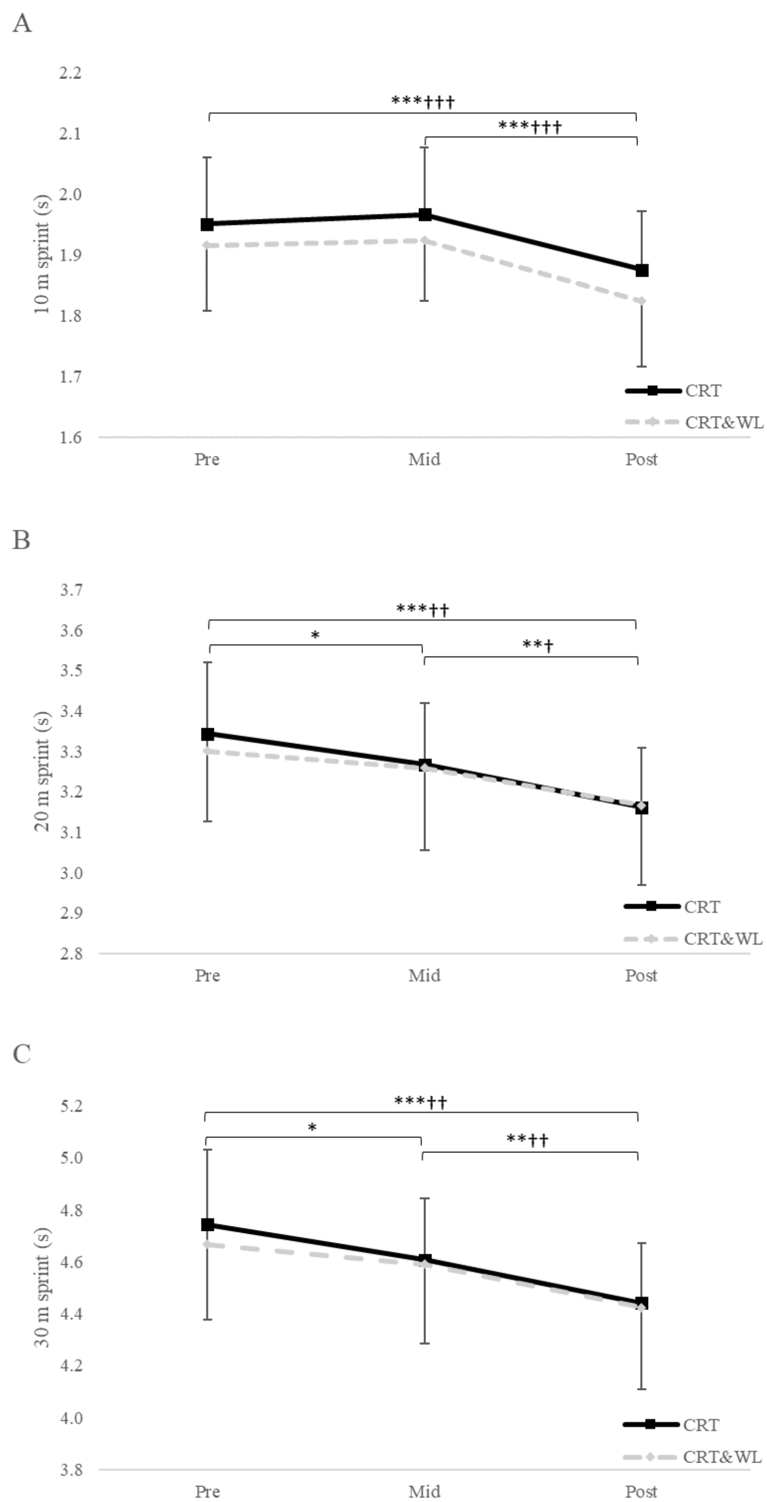

Figure 0.4. A) 10 meter sprint; B) 20 meter sprint; C) 30 meter sprint; CRT = combined resistance training; CRT&WL = combined resistance training & weightlifting; * significant within-group difference between time points for CRT group ($p < 0.05$), ** ($p < 0.01$), ** ($p < 0.01$), *** ($p \leq 0.001$); † significant within-group difference between times points for CRT&WL group ($p < 0.05$), †† ($p < 0.01$), ††† ($p \leq 0.001$); error bars represent standard deviation.

The mean percentage change and within-group effect sizes for the CRT and CRT&WL groups from pre to mid, mid to post and pre to post are shown in Table 5.2. When comparing between-group effects from pre to mid, there were small effects for 20-meter sprint, $IMTP_{ABS}$ and $IMTP_{REL}$ in favor of the CRT group (*d* = 0.22-0.49), whereas there were small effects for CMJ and RTSQ in favor of the CRT&WL group (*d* = 0.36 and 0.26, respectively). Comparing mid to post improvements showed small between-group effects for CMJ in favor of CRT&WL (*d* = 0.24), but HJ improvements were in favor of the CRT group (*d* = 0.23). Pre to post between-group comparisons revealed a small effect in favor of the CRT group for $IMTP_{REL}$ (*d* = 0.41). All other between-group comparisons were trivial.

Table 0.2. Individual percentage change (mean ± SD) and within-group effect sizes for motor skill performance assessments.

	Combined Resistance Training						Combined Resistance Training & Weightlifting					
	% change			Within-group effect size			% change			Within-group effect size		
	Pre-mid	Mid-post	Pre-post	Pre-mid	Mid-post	Pre-post	Pre-mid	Mid-post	Pre-post	Pre-mid	Mid-post	Pre-post
RTSQ	9.08 ± 17.08	0.40 ± 17.17	8.22 ± 17.36	0.45	-0.03	0.38	15.28 ± 27.263	3.91 ± 16.43	18.97 ± 31.55	0.56	0.15	0.74
$IMTP_{ABS}$	19.69 ± 18.25	7.09 ± 11.85	27.95 ± 22.95	0.53	0.18	0.78	18.65 ± 19.22	2.10 ± 8.43	20.66 ± 18.71	0.71	0.10	0.80
$IMTP_{REL}$	14.99 ± 18.69	2.85 ± 10.14	17.96 ± 21.06	0.86	0.16	1.07	13.65 ± 18.45	-3.11 ± 9.57	9.57 ± 16.71	0.67	-0.23	0.47
CMJ	-0.26 ± 16.44	10.52 ± 16.93	9.14 ± 19.64	-0.14	0.55	0.36	3.69 ±16.94	13.98 ± 20.29	17.05 ± 23.41	0.12	0.65	0.80
HJ	3.44 ± 13.85	6.86 ± 11.27	9.57 ± 11.73	0.17	0.47	0.62	-0.41 ± 8.40	7.63 ± 9.71	6.98 ± 10.95	-0.06	0.58	0.53
SMBT	2.47 ± 7.32	7.70 ± 7.53	10.14 ± 8.62	0.09	0.30	0.38	0.07 ± 5.82	8.61 ± 6.30	8.62 ± 7.89	-0.01	0.47	0.45
10 m sprint	0.87 ± 3.89	-4.58 ± 3.08	-6.07 ± 10.96	0.15	-0.95	-0.75	0.42 ± 2.24	-5.19 ± 2.86	-4.79 ± 3.36	0.07	-0.91	-0.83
20 m sprint	-2.18 ± 2.59	-3.18 ± 2.97	-5.30 ± 3.64	-0.41	-0.70	-0.98	-1.23 ± 1.80	-2.78 ± 2.49	-3.98 ± 2.87	-0.20	-0.46	-0.64
30 m sprint	-2.70 ± 3.02	-3.54 ± 3.13	-6.17 ± 3.77	-0.44	-0.71	-0.99	-1.54 ± 2.48	-3.59 ± 2.79	-5.08 ± 3.44	-0.23	-0.54	-0.71

RTSQ = resistance training skills quotient; $IMTP_{ABS}$ = absolute peak force of isometric mid-thigh pull; $IMTP_{REL}$ = ratio scaled peak force of isometric mid-thigh pull; CMJ = countermovement jump height; HJ = horizontal jump; SMBT = seated medicine ball throw.

Discussion

To our knowledge, this was the first study to compare the effects of a long-term periodized CRT program with or without weightlifting movements on the motor skill development of adolescent boys. The findings suggest that performance gains were similar between both groups, but the pattern of change varied. Movement competency and strength improved after initial training while power and speed responded positively to the higher intensities provided in the second half of the training program. The findings also suggest that movement competency and strength are trainable through periods of the adolescent growth spurt.

It was expected that due to the complex and explosive nature of the lifts, including weightlifting exercises in a CRT program would induce larger gains in movement competency, strength, power, and sprint performance. However, in general, our findings showed similar gains in strength, power and speed for both training groups. The CRT group, which had a higher proportion of exercises that allowed for greater external loading, showed similar increases as the CRT&WL group for strength as measured by $IMTP_{ABS}$ and $IMTP_{REL}$. The CRT&WL group, which had a higher proportion of high velocity movements, showed similar improvements to the CRT group in jump, throw and sprint performance. These results are in contrast to a recent meta-analysis (107 studies) that suggested power training improves jump performance more than strength training, whereas strength training improves strength and speed measures more than power training [54].

Adaptations to specific training types may also be influenced by maturation status [17-19, 199]. Specifically, previous studies in prepubertal children (aged 10-12 years) have found that strength, jump and sprint performance improved more after 12 weeks of weightlifting or plyometric [19] and a high velocity resistance training program [199] than age-matched controls participating in sports only. Additionally, six weeks of plyometric training elicited greater gains in squat jump and acceleration performance in pre-PHV children [18], whereas combined (traditional strength training + plyometrics) was most effective for sprint and jump performance in post-pubertal children [17, 18]. Together, the findings of these studies suggests that more mature children may require a greater neuromuscular stimulus and a variety of training methods to elicit gains in motor performance [70]. Therefore, the age (13.9-14.0 years) and maturational status (maturity offset = 0.1-0.3) of subjects in the current study might explain the similar training responses between both groups, as both groups were performing combined training approaches and had participants pre-, circa- and post-PHV.

Several factors in the current study may reflect the time course of the motor skill adaptations observed. The initial gain in resistance training skills and absolute and relative strength, as well as the delayed gains in sprint, jump and throw performance, may have resulted from the long-term periodized nature of the program. The participants used moderate volume (one to three sets, eight to 12 repetitions) and bodyweight or light resistance to develop resistance training competency in the first half of the intervention, which provided enough stimulus to induce gains in strength as they were relatively untrained. Throughout the current study, more complex exercises and greater external loads were used as the participants increased their technical competency and training age. This translated into greater gains in sprint, jump and throw performance in the second half of the training program. Previous research has found similar trends with a long-term periodized program [46]. Specifically, initial increases in back and front squat strength resulted in improved subsequent sprint performance [46], suggesting that strength may serve as a basis for power development. The current study showed that relatively low resistance training intensity may be adequate to stimulate moderate strength adaptations in adolescent boys with a relatively low training age. However, in order to promote long-term changes in performance and realize greater magnitudes of training-induced neuromuscular adaptation, participants will need to progressively overload and train with relatively higher resistance training intensities [11].

Another factor that may be responsible for the time course of gains in $IMTP_{ABS}$, $IMTP_{REL}$ and jump, throw and sprint performance in the current study is a lag between the realization of strength gains into power performance [200, 201]. The larger gains in movement skill and IMTP strength after the first 14 weeks of training are likely a result of greater neuromuscular coordination or mobility and maximal force output, respectively. However, the rapid rate of force development required for jumping, sprinting and throwing tasks was not realized until the last 14 weeks of training, when plyometric and resistance training intensity and complexity was highest. The greater intensity of traditional strength training, weightlifting and plyometric exercises in the latter half of the intervention may have helped the transfer of strength to more dynamic activities (e.g. CMJ, HJ, and SMBT) due to an increase in rate of force development via an enhanced neural drive [202]. Furthermore, increases in lower-limb muscular pre-activation [203], stiffness and power [204] as children mature may contribute to the larger gains in jump and sprint performance seen in the second half of the intervention. The results of this study demonstrate the importance of establishing movement competency and muscular strength before focusing on power development in youth, as well as the specificity of adaptations according to the emphasis of training.

Training age may also contribute to the aforementioned lag effect in power and sprint performance due to the type of training performed during different stages of development. For example, previous research has shown that larger strength gains occur during the first year than the second year of resistance training in adolescent male athletes [46]. Furthermore, Till et al. [205] also found that a group of rugby athletes (age 16-19 years) with a resistance training age of zero or two years saw greater annual gains in strength compared to a group with one year training experience. However, the older athletes in that study were likely all post-pubertal and therefore the results may not translate to an adolescent population. Regardless, this plateau period between initial and later strength gains may be partially explained by the emphasis of training during certain stages of development. Practitioners should ensure youth use light resistance and less complex movements when initially beginning resistance training before progressing to higher intensity and more complex movements as technical competency is established. The tests used to assess resistance training skills and strength were relatively new and simple, so the subjects responded to these novel stimuli more quickly than the more habitual complex tests involving more habitual activities such as sprinting, jumping and throwing. Therefore, they essentially have a higher training age for those tests and therefore take longer to respond to training. More importantly, however, the more complex activities do not respond as much until training intensity and complexity increase, which primarily occurred in the second half of the periodized program.

A limitation to this study is the lack of a control group, as the performance gains were not compared directly to similar aged subjects that did not complete the training. However, both groups, whose height, body mass and maturity offset did not differ significantly, were in an athletic development program and were all required to receive strength and conditioning support. Therefore, the purpose of this study was to compare responses to different resistance training programs in the sample population, with the overall dose of training kept similar between groups. The temporal responses of both groups provide support for the evidence of training effects beyond that of growth and maturation; while height and body mass improved at consistent rates between testing sessions, performance outcomes were more phasic and generally included a period of trivial change and a period of more substantial change. In periods where training effects were most evident, they are well beyond those expected for growth and maturation. For example, in the 14-week mid to post period, CMJ height improved by > 10% and sprint performance by 3-6%. This compares favourably to previous research. Specifically, in athletic boys aged between 13-17 years old completing plyometric, resistance or combined training twice a week for between 12-16 weeks, sprint performance has been reported to improve by 2-6% and CMJ height by 7-9% [206-209]. Even when considering the entire intervention period and converting to annual rates of improvement, boys in the present study improved CMJ height by a rate of > 26% per year and sprint performance by > 9% per year. These annual rates of improvement are well beyond those reported for the CMJ (6.9% per year) and sprint performance (2.7-3.1% per year) of boys in a talent development program but who received no resistance training [210].

The present study aimed to compare the effects of a CRT with or without weightlifting on the LTAD of adolescent boys. Major findings revealed largely similar performance gains between both groups. Interestingly, there were clear differences in the pattern of change across variables. In the first half of the year significant improvements in movement competency and strength were observed, while in the second half of the year jump, throw and sprint performance significantly improved. While height and body mass changed at consistent rates throughout the intervention, the different temporal responses shown for the performance variables likely aligned to the periodized design of the training program. Therefore, to effectively make long-term gains in motor skill performance, both coaches and athletes should trust in a long-term training process and adopt patience when pursuing long-term goals [14, 103].

Practical applications

Strength and conditioning programs that include weightlifting movements can be safely and effectively integrated within an academic schedule and result in gains in performance which supersede growth and maturation changes. Despite the proposed motor control challenges of learning weightlifting techniques, practitioners should consider the findings of the current study as evidence of how weightlifting movements can be successfully embedded within the physical education curricula to promote improvements in motor skill competency and physical fitness. Arranging the educational schedule into a series of training blocks, practitioners can effectively theme the delivery of weightlifting movements throughout the academic year to progressively teach and refine technical competency and enhance muscle strength in early stages of the year, before seeking adaptations in higher velocity movements in subsequent blocks. These approaches are in-line with the central tenets of current LTAD policy [14] and should only be delivered by qualified coaches with experience training youth.

Chapter 6: Effects of Combined Resistance Training and Weightlifting on Injury Risk Factors and Resistance Training Skill of Adolescent Males

This chapter has been accepted in the *Journal of Strength and Conditioning Research.*

Reference:

Pichardo AW, Oliver JL, Harrison CB, Maulder PS, Lloyd RS, Kandoi R. (in press). Effects of combined resistance training and weightlifting on injury risk factors and resistance training skill of adolescent males. *Journal of Strength and Conditioning Research.*

Preface

Two primary goals of athletic development programs are to improve performance and reduce the risk of injury. Chapter 5 demonstrated the effectiveness of resistance training with and without weightlifting on performance, which addressed the performance enhancement aspect. Specifically, both training groups significantly improved in jumping, sprinting and throw tasks over the year. Additionally, gains in movement skill and muscular strength preceded improvements in sprinting, jumping, and throwing, which aligns with athletic development models' recommendations to focus on technical competency and muscular strength early. This chapter aims to address the other goal of athletic development programs – reducing the risk of injury. An investigation into how the proposed training program (from Chapter 5) affects common injury risk factors such as landing kinematics, interlimb asymmetry, and movement skill may provide practitioners with valuable insight into the design and implementation of resistance training methods for adolescent boys.

Introduction

Lower-extremity injury incidence is heightened due to reduced neuromuscular control during PHV [171], a period of accelerated growth that occurs between ages 13.5-14.5 on average in males [34, 211]. Previous research has identified several factors such as jump landing kinematics [212, 213], interlimb asymmetry [214-216], and movement skill [78] that contribute to injury risk or reduced performance as result of this temporary loss in neuromuscular control. Much of the available research examining lower-extremity injury risk in adolescents has focused on knee kinematics during jump landing tasks [217-219]. One cross-sectional study of pre-, circa-, and post-PHV male soccer players demonstrated that a circa-PHV group experienced greater relative force during the landing of a single-leg CMJ, although knee valgus declined with maturation [213]. Furthermore, notable asymmetries of knee valgus during the tuck jump assessment were found in a cross-sectional study of and circa-PHV of 400 athletes from professional English soccer academies [220]. The tuck jump assessment is a practitioner-friendly assessment used to identify high-risk landing mechanics that requires little equipment [221], which makes it ideal for school and team settings. However, only one study has examined the changes in tuck jump scores after a training intervention [222]. Specifically, a 10-week injury prevention program that consisted of body weight exercises failed to improve tuck jump scores more than a control group performing regular soccer training, which suggests that a longer duration or greater training stimulus may be necessary to improve neuromuscular control. Since relatively short interventions using body weight exercises alone may not be sufficient to elicit improvements, further research investigating the effects of longer resistance training programs with greater external load on tuck jump assessment scores is warranted.

In addition to lower-extremity mechanics during jump-landing tasks, interlimb asymmetry of jump, strength, and balance tests may contribute to risk of injury [223] or reduced performance [214-216]. For example, higher injury rates were associated with isokinetic strength asymmetry measures greater than 15% in collegiate athletes [224], though limited research has examined this threshold in young athletes. In terms of the impact of interlimb asymmetry on performance, Bishop et al. [215] found strong relationships between single-leg jump asymmetry and sprint performance (r = 0.79-0.87), as well as change of direction performance (r = 0.63-0.85) in elite U16 soccer players. Another study by Bailey et al. [216] found significant relationships between IMTP interlimb asymmetry and bilateral jump height (r = -0.47 to -0.52). Finally, high school basketball players with an asymmetry greater than or equal to 4 cm for the anterior reach distance of the Star Excursion Balance Test (SEBT) were two and a half times more likely to sustain a lower-extremity injury during the season [223]. Several studies have demonstrated that targeted training can reduce asymmetries [225, 226], but these studies were conducted in a sporting environment, where a more targeted approach can be delivered by sport coaches. Thus, further investigation is needed to determine the effects of a school-based resistance training program on interlimb asymmetry of adolescent males. Since interlimb asymmetries are linked to injury and reduced performance [216, 223], practitioners should aim to reduce asymmetry values during adolescence when risk of injury is greater due to decreased neuromuscular function.

Numerous movement skill assessments have been shown to be reliable in youth populations [133, 134, 227-229]. When practicing within a school setting, practitioners should aim to choose a movement assessment that can be efficiently implemented given the time constraints of school curriculum. The RTSB was designed as a measurement tool used to evaluate the efficacy of school-based resistance training programs on movement skill competency [133]. Given the aims of the RTSB, it was designed with the constraints of a school setting in mind and therefore requires minimal equipment and can easily be conducted by educators and pediatric researchers. However, only two studies have examined changes in resistance training skill after an intervention [96, 230]. These studies found significant improvements in resistance training skill of an adolescent aged training group compared to a control group after a 10-week [96] and 20-week intervention [231]. These improvements were sustained up to 18 months following cessation of training [96, 232], which suggests students and athletes retain these skills once developed. Due to the heightened neural plasticity associated with childhood, resistance training skills should be taught as early as possible to aid in LTAD [3].

Resistance training interventions have been lauded for their effectiveness in decreasing injury risk factors [233] and improving movement [234]. Previous research suggests weightlifting exercises specifically may help reduce injury by improving the kinetics and kinematics associated with landing, cutting, and deceleration movements [235]. Weightlifting training, which refers to the snatch, clean and jerk, and their derivatives, involves a rapid concentric action, followed by an eccentric action during the catch, or absorption phase following the second pull - a pattern similar to landing and cutting activities. Of note, Suchomel et al. [193] found that exercises without the catch phase of the lift produce greater load absorption demands than a hang clean (which includes a catch), which indicates that training with derivatives of the full weightlifting lifts can be a valuable method to improve load absorption and reduce risk factors for injury. However, research utilizing resistance training and weightlifting in youth populations has primarily measured performance based outcomes such as strength [21], speed [19], and jump performance [20], which neglects other potential benefits such as reducing injury risk or enhancing resistance training skill. Therefore, the purpose of this study was to investigate how CRT with or without weightlifting movements affect injury risk factors, such as jump landing kinematics and interlimb asymmetry, as well as resistance training skill.

Methods

Experimental Approach to the Problem

A cluster randomized controlled trial was used to determine the effects of CRT, CRT&WL, or regular physical education curriculum (CON) on resistance training skill and risk factors for lower-extremity injuries in adolescent males after an academic year. Boys enrolled in an athlete development programme were matched by maturation and CMJ height, then divided into one of two training groups: CRT or CRT&WL training. Two age-matched physical education classes comprised the control group. The CRT group completed a combination of traditional resistance training and plyometric training, whereas the CRT&WL group also completed traditional resistance and plyometric training but replaced two or three of the strength-based exercises with weightlifting derivatives. Both training groups completed this training twice per week, in addition to regular physical education curriculum two to three times per week. When data collection weeks and school holidays were accounted for, each group completed 28 total weeks of training. The CON group completed their regular physical education curriculum two to three times per week. The physical education classes consisted of large and small ball sports to improve hitting, striking, catching, throwing, kicking, and kinaesthetic awareness, as well as an aquatics unit at a local pool. All participants completed the same battery of tests pre-, mid- (14 training weeks) and post-training (28 training weeks), which included a tuck jump assessment, single-leg HJ, modified Star Excursion Balance Test (SEBT), IMTP, and RTSB.

Subjects

Sixty-seven year nine and ten boys (aged 12-14 years) from a secondary school in New Zealand volunteered to participate in this study. Forty boys from the school's athlete development program were matched by maturity offset [120] and CMJ height and divided into either the CRT (n = 21) or CRT&WL group (n = 19), whereas the CON group (n = 27) was comprised of two age-matched physical education classes. Participant characteristics are presented in Table 1. All participants were engaged in a physical education curriculum but had less than nine months of any formal resistance training experience. Parental informed consent and participant assent were obtained before the study and ethical approval was granted by the Institutional Research Ethics Committee.

Table 0.1. Anthropometric data (mean ± SD) for pre-, mid- and post-test.

	CRT (*n* = 21)			CRT&WL (*n* = 19)			CON (*n* = 27)		
	Pre	Mid	Post	Pre	Mid	Post	Pre	Mid	Post
Height (cm)	165.0 ± 10.2	167.6 ± 10.2	170.0 ± 10.0	168.1 ± 8.4	171.6 ± 7.4	172.9 ± 7.6	165.1 ± 9.3	167.4 ± 8.2	170.2 ± 7.7
Body mass (kg)	55.8 ± 12.4	58.8 ± 12.9	60.9 ± 12.7	56.7 ± 10.9	60.0 ± 11.7	64.2 ± 12.0	56.6 ± 15.1	60.8 ± 15.7	61.2 ± 15.6
Maturity offset (years)	0.0 ± 0.8			0.2 ± 0.8			0.0 ± 0.9		

CRT = combined resistance training; CRT&WL = combined resistance training & weightlifting; CON = control.

Procedures

Testing was completed during standard physical education classes on two non-consecutive days. The first testing session included collection of anthropometric measures, IMTP, and the single-leg HJ, whereas the second session included the RTSB, the tuck jump assessment, and the modified SEBT. Participants completed a standardized dynamic warm-up that lasted approximately eight minutes and included body weight squats, lunges, and push-ups, as well as three submaximal sprints and jumps at 50, 70, and 90% effort. The athletic development and physical education classes were divided into even groups and performed the tests in a randomized order on the first testing session, but then performed the tests in the same order on subsequent testing sessions. This approach was used due to the number of participants and the time constraints of the school curriculum.

Anthropometrics

Standing height was measured to the nearest 0.1 cm using a stadiometer (Model: WSHRP; Wedderburn, New Zealand). Seated height was measured to the nearest 0.1 cm using a meter stick taped to a wall above a 40 cm wooden box. Body mass was measured to the nearest 0.1 kg using a digital scale (Model: TI390150K; Tanita, New Zealand). Maturity offset was determined using the following regression analysis based on age, body mass, standing height, and seated height [120]: Maturity offset = -(9.236 + 0.0002708 * leg length and sitting height interaction)-(0.001663·age and leg length interaction) + (0.007216·Age and sitting height interaction) + (0.02292 * weight by height ratio). This equation, which has a standard error of 0.57 years in males, is a non-invasive method to predict maturity status [120].

Tuck Jump Assessment

Participants stood with their feet on two parallel pieces of tape 35 cm apart, connected by a horizontal portion, forming an H-shape [236]. Participants were instructed to jump as high as possible, raise their knees as high as possible and begin the next jump immediately after landing. A research assistant demonstrated proper technique prior to participants completing the assessment. Each participant performed the tuck jumps for 10 seconds, or until technique declined and they were unable to complete another repetition. Digital cameras placed in the frontal and sagittal planes were used to record the assessment for retrospective rating according to criteria from Myer et al. [221]. The tuck jump assessment has shown strong between-session reliability (ICC = 0.88) in young male athletes [237].

Single-leg Horizontal Jump

The single-leg HJ was measured using a tape measure affixed to a wooden gymnasium floor. Participants were instructed to place hands on hips, stand on one leg with their toe behind a line, then jump as far as possible and land on two legs. Distance was recorded from the heel of the rearmost foot upon landing to the nearest centimetre. Trials were not valid if the participant's hands came off the hips or they moved one of their feet upon landing. Each participant performed two jumps with each leg and were given approximately one-minute rest between jumps. The best jump distance was used for asymmetry analysis. Horizontal jump distance has shown high reliability in adolescents (ICC = 0.63-0.96, CV = 3.8-9.4%) [170].

Isometric Mid-thigh Pull

Participants performed the IMTP with a fixed barbell standing on two portable force platforms sampling at 100 Hz (Pasco, Roseville, CA). The force plates were placed on dense, incompressible rubber mats that were added or taken away to adjust the height of the bar in one cm increments for each participant. A self-selected posture which replicated the second pull of a clean was used, as previous research has demonstrated high reliability with this technique [238] (Figure 6.1). Each participant had an upright torso with hands placed outside their legs, the bar positioned at mid-thigh, and knee and hip angles of approximately 125-145° and 140-150°, respectively [175]. Participants were instructed to push their feet into the ground as hard and as fast as possible. A countdown of *"Three, two, one, pull!"* was given, at which point each participant pulled maximally for approximately three seconds with verbal encouragement provided. Each participant completed two trials with approximately one-minute rest. Trials were discounted and repeated if there was a noticeable countermovement, or if the participant lost grip. The best trial on each leg was used for asymmetry analysis. Peak force reflected the maximum force (N) generated during each trial for each leg and was analysed using custom Labview software (National Instruments). This protocol has shown high between-session reliability (ICC = 0.96, CV = 4.61%) in adolescent males [194].

Figure 0.1. Isometric mid-thigh pull setup.

Star Excursion Balance Test

The reach distance of the anterior, posteromedial, and posterolateral direction of the SEBT were measured using three tape measures taped to the floor. A goniometer was used to fix the posterolateral and posteromedial tape measures at a 135° angle. Participants were instructed to place their big toe at the intersection of the three tape measures, place their hands on their hips, and reach as far as possible along the tape in each direction. Each participant performed two successful trials in each direction in a randomized order. A trial was discounted and repeated if one of the following occurred: the participant's hands were removed from the hips, their stance foot or heel was moved, they did not return to the starting position in a controlled manner, or they heavily placed their reach foot on the ground to retain balance. The intra-rater reliability of the SEBT has been high (ICC = 0.84-0.99) in previous studies assessing secondary school students [212, 223].

Resistance Training Skills Battery

Participants were screened using a modified version of the RTSB, which provides an assessment of basic resistance training skill competency [133]. This screen includes six body weight movements: body weight squat with a dowel rod, lunge, suspended row, standing overhead press, front support with chest touches and push-up, which were performed in a randomized order. Participants performed four repetitions of each movement and were filmed from the frontal and sagittal plane with an iPad (3rd and 4th generation, Apple Inc., USA) on a tripod one meter high and three meters from the participant. Each movement was rated retrospectively by an experienced rater according to the criteria established by Lubans et al. [133]. The best repetition of each movement was scored according to four (push-up and suspended row) or five (body weight squat, lunge, standing overhead press and front support with chest touches) movement criteria. The resistance training skills quotient (RTSQ) was determined by adding the score for each skill together, which results in a score of 0-56. Although the traditional RTSB requires participants to perform two sets of four repetitions for each movement, only one set of each exercise was performed due to time restrictions of the school curriculum, so the score for each exercise was doubled for a total of eight or 10 for movements scored out of four or five criteria, respectively. A pilot study undertaken with a small sub-sample of 10 participants rated and re-rated seven days later demonstrated acceptable relative reliability for individual movements (ICC = 0.71-0.95) and RTSQ (ICC = 0.97), which is comparable to the original protocol from Lubans et al. [133] (ICC = 0.67-0.88) and an adapted version from Bebich-Philip et al. [239] (ICC = 0.87-0.97).

Training Program

Guidelines for the training programs is shown in Table 2 and has been described elsewhere in more detail [240]. Briefly, both training groups completed 28 weeks of training over the course of an academic year. Both groups performed the same speed, agility, and plyometric exercises outside on a turf field or inside a gymnasium. However, the resistance training exercises within the weight room varied depending on group. The CRT group performed traditional resistance training exercises, whereas the CRT&WL group replaced two or three of the main exercises with weightlifting exercises and derivatives that were similar in range of motion and muscles used. For example, when the CRT group performed a deadlift, the CRT&WL group performed a clean pull. Volume was matched by sets and reps, but not total volume load since the movements were loaded to different degrees. Movements and load were assigned and progressed based on technical competency, similar to suggested approaches for athletes with varying skill levels [128, 241]. All weight room training was supervised, and feedback was given by a certified strength and conditioning specialist with a USA Weightlifting certification. There were no injuries that caused a loss in training time as a result of the training program.

Statistical Analysis

Descriptive statistics (mean ± SD) were calculated for all variables. Kolmogorov-Smirnov tests revealed that the RTSQ were the only normally distributed data. Therefore, for the RTSQ, a 3 × 3 repeated-measures analysis of variance (ANOVA) was used to determine between-group differences at pre-, mid-, and post-test, as well as within-group differences between time points. A Maulchy's Test was used to assess sphericity and if violated, the Greenhouse-Geisser adjustment was applied. Bonferroni post hoc tests were used to determine the location of any significant differences. For the non-normally distributed data (individual RTSB skills and asymmetry measures), Kruskal-Wallis tests were used to determine between-group differences at pre-, mid-, and post-test with Mann-Whitney U post hoc tests used to determine the location of any significant differences. Friedman tests were used to determine within-group effects of time, with a Wilcoxon signed rank test used to determine significant changes between time points. Within-group effect sizes for the RTSQ were calculated in Microsoft Excel (Version 16) and were interpreted according to Cohen's *d* statistic. Interlimb asymmetry for the single-leg HJ, IMTP, and SEBT was calculated using the following equation: [(highest performing limb – lowest performing limb) / highest performing limb] × 100 [212]. Intrasession reliability was calculated using pairwise comparisons on log-transformed data to reduce the effects of any non-uniformity of error [183]. The typical error was expressed as a CV percentage to determine absolute reliability and the ICC was used to determine relative reliability. Average participant percentage change between time points was also calculated for each group using Excel. The descriptive statistics, repeated measures ANOVA, and non-parametric tests were all calculated using

SPSS version 25 (SPSS Inc., Chicago, IL, USA). Statistical significance was set at an alpha level of $p \leq 0.05$ for all tests.

Results

All variables showed acceptable absolute (CV ≤ 15%) and relative (ICC ≥ 0.70) intrasession reliability, respectively: IMTP (CV = 10.0-11.1%, ICC = 0.89-0.91); single-leg HJ (CV = 5.2-5.5%, ICC = 0.89-0.90); SEBT (CV = 4.3-5.7%, ICC = 0.72-0.81). For the tuck jump assessment, there was no difference between groups at baseline ($p = 0.96$). The CRT and CRT&WL groups scored significantly better than the CON group at the mid-test ($p = 0.01$ and 0.04, respectively) but only the CRT group scored significantly better than the CON group at post-test ($p = 0.03$). The CRT group significantly decreased their tuck jump score from pre- to mid- ($p = 0.04$, -8.9%, $d = -0.68$) and pre- to post-test ($p = 0.01$, -20.4%, $d = -0.39$), as shown in Figure 6.2. The CRT&WL and CON group did not significantly improve between any two time points.

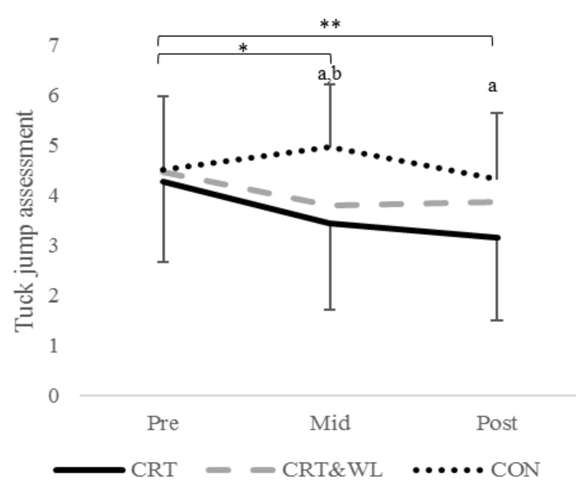

Figure 0.2. CRT = combined resistance training; CRT&WL = combined resistance training & weightlifting; CON = control; * significant within-group change for CRT group ($p \leq 0.05$), ** ($p \leq 0.01$); a = CRT group significantly higher than CON group ($p \leq 0.05$); b = CRT&WL group significantly higher than CON group ($p \leq 0.05$).

The asymmetry measures and within-group changes are displayed in Table 6.2. There were no between-group differences for any of the asymmetry measures at any time point (all $p \geq 0.10$). Asymmetry for the IMTP significantly decreased from mid- to post-test for the CRT&WL group ($p = 0.02$, -8.65%, $d = -0.76$). Anterior reach asymmetry significantly decreased from mid- to post-test for the CON group ($p = 0.03$, -3.00%, $d = -0.54$). The CRT group's posterolateral reach asymmetry significantly decreased from pre- to mid-test ($p = 0.01$, -2.70%, $d = -0.92$), whereas the CON group significantly decreased from pre- to mid- ($p = 0.002$, -2.77%, $d = -1.00$) and pre- to post-test ($p = 0.002$, -2.23%, $d = -0.81$). There were no within-group changes for single-leg HJ or posteromedial reach asymmetry (all $p > 0.05$).

Table 0.2. Percentage asymmetry measures for the single-leg horizontal jump, isometric mid-thigh pull, and modified Star Excursion Balance Test.

	CRT			CRT&WL			CON		
	Asymmetry %			Asymmetry %			Asymmetry %		
	Pre	Mid	Post	Pre	Mid	Post	Pre	Mid	Post
Single-leg horizontal jump (m)	7.1 ± 5.1	5.7 ± 4.0	6.3 ± 4.6	6.1 ± 3.7	5.4 ± 6.7	5.4 ± 4.9	8.9 ± 6.9	7.4 ± 7.6	5.8 ± 5.9
Isometric mid-thigh pull (N)	17.2 ± 13.5	17.5 ± 11.9	12.8 ± 8.9	15.2 ± 9.6	21.0 ± 13.9	12.3 ± 8.2[b]	17.2 ± 13.3	15.7 ± 9.0	18.4 ± 12.8
Anterior reach (cm)	4.0 ± 3.4	3.4 ± 3.4	2.7 ± 2.5	6.3 ± 4.5	4.8 ± 4.2	5.4 ± 4.6	4.8 ± 4.5	7.0 ± 6.8	4.0 ± 3.9[b]
Posteromedial reach (cm)	4.6 ± 3.8	3.9 ± 2.7	2.8 ± 2.3	4.9 ± 4.5	3.9 ± 3.2	3.6 ± 3.2	4.6 ± 4.2	3.5 ± 2.8	5.0 ± 5.2
Posterolateral reach (cm)	4.8 ± 3.4	2.0 ± 2.3[a]	3.1 ± 3.4	3.9 ± 3.6	3.1 ± 2.7	3.8 ± 3.5	4.6 ± 3.3	1.9 ± 2.3[a]	2.4 ± 2.1[a]

The repeated measures ANOVA showed there were no significant group × time interactions for the RTSQ ($p = 0.81$), but there was a significant main effect for group ($p < 0.001$) and time ($p < 0.001$). Post hoc analysis revealed that the CRT group scored significantly higher than the CRT&WL group at baseline ($p = 0.05$) and significantly higher than the CON group at each time point (pre: $p = 0.004$, mid: $p = 0.002$, and post: $p = 0.002$). However, both the CRT and CRT&WL groups significantly improved from pre- to post-test (CRT: $p = 0.03$, 9.2%, $d = 0.53$); CRT&WL: $p = 0.002$, 17.6%, $d = 1.00$) (Figure 6.3).

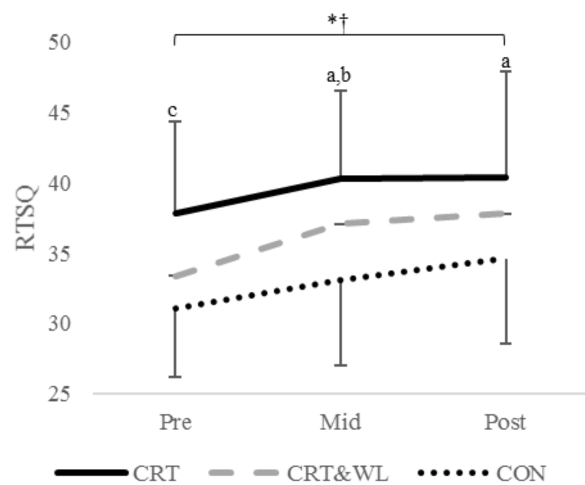

Figure 0.3. CRT = combined resistance training; CRT&WL = combined resistance training & weightlifting; CON = control; * significant within-group change for CRT group ($p \leq 0.05$); † significant within-group change for CRT&WL group ($p \leq 0.05$); a = CRT group significantly higher than CON group ($p \leq 0.05$); b = CRT&WL group significantly higher than CON group ($p \leq 0.05$); c = CRT group significantly higher than both groups ($p \leq 0.05$).

For the standing overhead press, all groups were similar at baseline but the CRT and CRT&WL groups scored significantly better than the CON group at the mid- ($p = 0.01$ and 0.04) and post-test ($p = 0.04$ and 0.002). Each training group significantly improved their score from pre- to mid- (CRT = $p < 0.01$, 31.3%, $d = 0.91$; CRT&WL = $p < 0.05$, 26.8%, $d = 0.75$) and pre- to post-test (CRT = $p < 0.01$, 40.1%, $d = 1.12$; CRT&WL = $p \leq 0.001$, 33.3%, $d = 1.35$) (Figure 6.4A). There were no significant between-group differences or within-group changes for the front support with chest touches (all $p > 0.05$) (Figure 6.4B). For the body weight squat, there were no between-group differences at any time points, but the CON group significantly improved from pre- to post-test ($p < 0.01$, 37.1%, $d = 0.71$) (Figure 6.4C). For the lunge, the CRT and CRT&WL groups scored significantly better than the CON group at baseline ($p \leq 0.001$ and 0.003, respectively), but there were no between-group differences at any other time point and no significant within-group changes (Figure 6.4D). For the suspended row, both the CRT&WL and CON groups significantly improved performance over the first half of the intervention (CRT&WL = $p < 0.01$, 51.0%, $d = 1.24$; CON = $p < 0.01$, 21.0%, $d = 0.53$) and the CRT&WL group decreased in performance over the last half ($p < 0.05$, -13.2%, $d = -0.74$) (Figure 6.4E). Lastly, the CRT group scored significantly better than the CRT&WL group ($p = 0.03$) and CON group ($p = 0.002$) on the push-up at the mid-test, but there were no significant within-group changes for any group (Figure 6.4F).

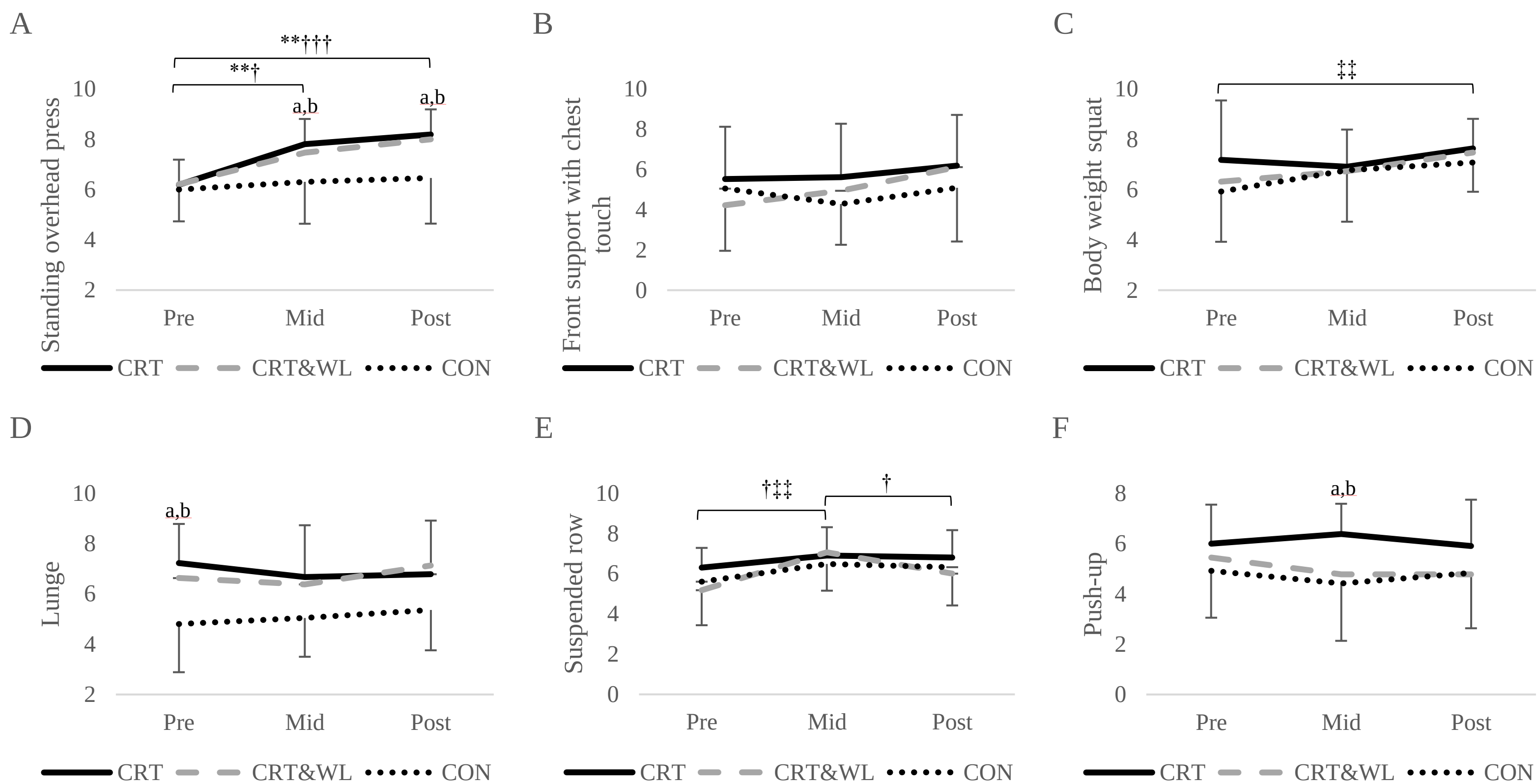

Figure 0.4. A) standing overhead press; B) front support with chest touches; C) body weight squat; D) lunge; E) suspended row; F) push-up; CRT = combined resistance training; CRT&WL = combined resistance training & weightlifting; CON = control; ** significant within-group change for CRT group ($p \leq 0.01$); † significant within-group change for CRT&WL group ($p \leq 0.05$); ††† ($p \leq 0.001$); ‡‡ significant within-group change for CON group ($p \leq 0.01$); a = CRT group significantly higher than CON group ($p \leq 0.05$); b = CRT&WL group significantly higher than CON group ($p \leq 0.05$).

Discussion

This study examined the effects of an academic year of CRT or CRT&WL versus traditional physical education curriculum on measures of jump landing kinematics, interlimb asymmetry of several common field-tests, and resistance training skills of adolescent males. Overall, the findings suggest that both training groups scored significantly better than the CON group on the tuck jump assessment after 14 weeks of training. However, only the CRT group significantly improved tuck jump performance between any two time points and scored better than the CON group after 28 weeks of training. The effects of CRT and CRT&WL on interlimb asymmetry were inconsistent and varied according to test protocol. Furthermore, both CRT and CRT&WL were effective in improving resistance training skill competency, although the inclusion of weightlifting training resulted in a greater percentage improvement than CRT alone.

The CRT group was the only group to significantly improve their tuck jump assessment score. Additionally, the CRT group reduced their score by 1.11 points, which is greater than the typical error of 0.90 and 1.01 identified in pre-PHV and post-PHV groups, respectively [237]. However, despite a reduction for the CRT&WL group, their improvement of 0.60 points was lower than the previously mentioned typical errors [237], which suggests their improvement could simply be due to natural variation in tuck jump performance. In contrast to the findings from this study, a 10-week intervention using body weight exercises failed to improve tuck jump assessment scores more than a control group in similarly aged female athletes [222]. The current study included 28 weeks of training with loads in excess of body weight, which indicates that longer duration training interventions using greater external loads may be necessary to significantly improve tuck jump assessment scores. Interestingly, CRT&WL training did not improve tuck jump assessment scores despite significant gains in resistance training skill. This suggests that improvements in resistance training skill may not transfer to more intense movements, such as repetitive jump landings. Therefore, practitioners can include a combination of traditional resistance, plyometric, and weightlifting training to improve jump landing kinematics and movement competency.

In general, no differences were seen in asymmetry measures between time points or groups. Single-leg HJ jump asymmetry of the participants in the present study are comparable to the 7% found in circa-PHV males in a previous cross-sectional study [212]. Interestingly, the CON group decreased their single-leg HJ asymmetry more than both training groups over the course of the study. One factor that could have contributed to this finding was that the training groups were comprised exclusively of athletes, whereas the control group was a mixture of athletes and non-athletes. Rugby and soccer are common sports in New Zealand, so the athletes in the training groups may have propagated their asymmetry over the course of the intervention from the repetitive kicking exposure whereas single-leg HJ asymmetry naturally decreased for the CON group with regular physical education curriculum. Despite the greater reduction in asymmetry seen in the CON group, each group's mean single-leg HJ asymmetry was < 10% at each time point, which is below the common threshold used for return-to-play scenarios in youth athletes [242]. Therefore, neither of the groups as a whole were considered at greater risk of injury as a result of abnormally high asymmetry. Although asymmetry values of the single-leg HJ are relatively low compared to asymmetry during sprinting (14.7-20.2%) [243] and single-leg vertical jumps of similar aged athletes (9.0-15.0%) [212, 215], it is potentially less sensitive to detect asymmetry above established thresholds. Nonetheless, a single-leg HJ assessment requires very little equipment and is therefore still a valuable tool for practitioners to detect changes in asymmetry over time. Since much of the existing research examining asymmetry in youth males is cross-sectional in nature [212, 213, 215, 220, 243], further research examining the effects of training programs on lower-extremity asymmetry is needed.

The RTSQ improved the most in the CRT&WL group, whereas the CRT group experienced similar moderate improvements as the CON group. This may be due in part to the nature of weightlifting movements, which require greater neuromuscular coordination than traditional resistance training exercises [244]. Despite the differences in raw RTSQ improvements (CRT = 3.3; CRT&WL = 5.0; CON = 3.0), each group improved their RTSQ more than the typical error of 2.5 reported by Lubans et al. [133], which suggests these changes were not due to natural variation. However, only the training groups improved significantly from pre- to post-test, which indicates the efficacy of a school curriculum training program that includes variations of the key movement patterns included in the RTSB (e.g. squat, push-up, standing overhead press, and core stability exercises). Only one other study has examined the effects of an intervention on resistance training skill competency [230]. The intervention group in that study improved their RTSQ more than a control group after a 20-week intervention. However, the participants were adolescent boys at risk of obesity with a baseline RTSQ of ~31 points, which was lower than all three groups in the current study (32-39 points). Thus, RTSQ may be more sensitive to improvements due to the health status and low baseline scores of those participants. Based on the findings of the current study, school-based resistance training programs may improve resistance training skill competency, although the inclusion of weightlifting training may provide a greater change due to the greater technical and coordinative demand of the exercises.

When examining individual skills, both training groups significantly improved the standing overhead press and were significantly higher than the CON group at the mid- and post-test. Additionally, the training groups improved more than the typical error of 1.0 [133] for the standing overhead press (CRT = 2.0; CRT&WL = 1.8), whereas the CON group did not (CON = 0.5). One possible reason for the large improvement in standing overhead press is that it is a less common movement pattern than the other RTSB skills that occur naturally during sport or physical education curricula, such as squatting or lunging. Therefore, the novelty and inclusion of overhead exercises such as standing dumbbell and barbell overhead presses, push presses, push jerks, and split jerks in the training program likely contributed to the large improvements seen in both training groups. The previously mentioned study that measured resistance training skill competency over a 20-week intervention did not include a breakdown of individual skill improvement [230], so there is no comparative literature available that has tracked changes in individual skills after resistance training programs. Further research investigating the effects of training programs on resistance training skill is needed to validate these findings, as well as determine if training responses are similar in different populations.

In summary, the results of this study showed that CRT improved tuck jump scores more than CRT&WL and regular physical education curriculum. Additionally, both CRT&WL and CRT significantly improved resistance training skill after an introductory resistance training program. Cumulatively, practitioners can use a combination of traditional resistance training, plyometric, and weightlifting training to reduce injury risk factors associated with jump landings and improve resistance training skill competency.

Practical applications

The findings of this study suggest that resistance training with or without weightlifting movements may improve resistance training skill competency, particularly for overhead movements. Combined resistance and plyometric training may provide greater improvements in jump landing kinematics. However, the inclusion of weightlifting movements within the resistance training program may provide greater improvements in movement skill, possibly due to the increased complexity of these lifts. Despite the benefits of weightlifting training, practitioners should ensure that young athletes are exposed to appropriate progression, with technical competency never compromised in the pursuit of lifting greater loads. This study highlights the effectiveness of a comprehensive resistance training program integrated into secondary school curriculum by a certified and qualified strength and conditioning coach.

Chapter 7: Summary, Practical Applications, Reflections, Limitations, and Future Research Directions

Summary

The purpose of this thesis was to examine the benefits of a CRT and CRT&WL program that was implemented twice per week in a secondary school's advanced physical education curriculum. Several general models of athletic development (DMSP, LTAD, YPD) have highlighted the role of maturation on training responses. Moreover, they suggest that youth should engage in a variety of movements and sports to develop a broad foundation of motor skills (Chapter 2). Stages from these general models were used in subsequent strength training, plyometric training, weightlifting, and fitness component models and emphasized the importance of technical competency when progressing training intensity, exercise complexity, and training structure. The collection of models suggests traditional strength, plyometric, and weightlifting training can improve fitness components such as movement competency, strength, power and speed. To help guide a practitioner implementing these principals, an applied example of an introductory resistance training program was presented (Chapter 3). This example provided greater insight into what a macrocycle, mesocycle, microcycle, and training session may look like for a young athlete with limited training experience. Specifically, youth with a relatively low training age should focus on athletic motor skill competencies using body weight and light resistance to establish technical competency and build general strength and coordination. As technical competency and training age improve, the intensity and complexity of movements should be increased and can include more traditional strength training and weightlifting exercises.

To determine the relative influence of maturation, strength, and movement competency on motor skill performance in adolescent boys, a cross-sectional approach examining year nine and ten students was used (Chapter 4). Despite being of similar chronological age there was a broad range of maturity across the participants (-2.0 to 2.3 years PHV). Maturity offset showed significant small to moderate correlations with sprint, jump and throw measures (r = 0.23-0.34, all $p < 0.05$) and a large relationship with $IMTP_{ABS}$ (r = 0.69). Relative IMTP strength showed significant small to large correlations with all performance variables (r = 0.27-0.61) and generally showed larger correlations than absolute strength. Furthermore, relative strength was the main predictor for all but two variables (HJ and SMBT), combining with maturity and absolute strength to explain between 21-76% of performance. Although movement competency did not provide a significant contribution when other variables were simultaneously considered, there were small to moderate correlations with sprint (r = 0.21-0.37) and YYIRTL1 (r = 0.28), suggesting movement competency is more strongly related to coordination of repeated contralateral movements during running compared to single effort bilateral movements, such as the jumps and throw. Given these findings, resistance training programs should emphasize muscular strength and movement skill development. Additionally, practitioners should understand the influence of maturation on athletic performance and use relative measures of strength and power to reduce the risk of a biased perception of an athlete's athleticism, particularly during PHV when maturity status varies greatly.

Given the importance of strength and movement competency for athletic performance, it was important to understand how different methods of resistance training improve motor skill performance (Chapter 5). After the participants followed a resistance training program with or without the inclusion of weightlifting movements for an academic year, this thesis shows both are similarly effective in improving motor skill performance of adolescent boys (Chapter 5). However, the pattern of change was different between variables; both training groups experienced larger improvements in movement skill and IMTP strength after the first 14 weeks of training, whereas larger improvements for sprint, jump, and throw occurred in the second 14 weeks of training. This suggests that adolescents must establish a foundation of strength and movement competency before gains in power and speed development manifest. Chapter 6 further investigated the influence of these training programs on risk factors for injury and resistance training skill. Only the CRT group significantly improved their tuck jump scores after 14 weeks (8.9%) and 28 weeks of training (20.4%). Their score was significantly better than the CON group at mid- and post-intervention. Additionally, both training groups significantly improved resistance training skill, although the CRT&WL

group improved more than the CRT group (17.6% compared to 9.2%). However, the effects of resistance training and weightlifting on interlimb asymmetry remain unclear. Based on these results, CRT appears to be most effective in improving jump landing kinematics whereas the inclusion of weightlifting exercises may provide greater magnitude improvements in resistance training skill.

In summary, existing conceptual models support the use of strength training, plyometrics, and weightlifting to improve athletic performance. Moreover, secondary school curriculum is a good avenue for implementing resistance training due to the inherent high compliance rate and access to training facilities. Both CRT and CRT&WL appear to be effective in improving motor skill performance in adolescent males, with gains in strength and movement competency preceding gains in jump, sprint, and throw performance. Furthermore, weightlifting training appears to improve movement competency more than CRT, whereas CRT improves landing kinematics more, likely due to greater improvements in relative strength. Therefore, practitioners should use a combination of strength, plyometric, and weightlifting training in the physical development of adolescent boys.

Practical applications

This thesis suggests that young males engaging in a comprehensive strength and conditioning program can make significant improvements in athletic performance and landing kinematics. It also shows that athletes new to an athletic development program may increase their strength and movement competency prior to seeing improvements in sprint, jump, and throw performance, likely due to an emphasis on technical competency using relatively light loads before progressing to more complex movements with greater resistance. Additionally, the physiological adaptations to resistance training over the course of an academic year may be similar with or without the inclusion of weightlifting exercises, but an advantage of including weightlifting in training programs is that youth athletes will also learn the skill of weightlifting alongside improving physical fitness. Practitioners can choose to utilize weightlifting exercises based on their experiences and ability to coach the movements. Becoming competent at weightlifting may be desirable for youth athletes who progress through a performance pathway, as weightlifting will feature in the training of many elite athletes.

Based on the findings of this thesis, the following practical applications may help coaches, teachers, and researchers with the design and implementation of resistance training programs in the school curriculum:

1. Muscular strength, particularly relative strength, influences motor skill performance and should therefore be a primary emphasis throughout development.
2. Strength is more useful than maturity to inform training. Irrespective of maturity, strength should be a training priority for someone that is relatively weak.
3. Overall movement competency may contribute more to repetitive contralateral movements, such as running, as opposed to single-effort bilateral movements, such as jumping.
4. An introductory resistance training program with weightlifting exercises allows athletes to learn a new skill while also significantly improving motor skill performance over the course of an academic year.
5. The improvement of movement competency and strength precedes subsequent improvements in running, jumping, and throwing and should therefore be prioritized early in a resistance training program.
6. Traditional strength training may provide greater improvements than weightlifting training in jump landing kinematics although weightlifting training may provide greater improvements in resistance training skill.

Reflections

Previous literature has highlighted the value of reflective practice in coaching [245-247]. Through a spiral of appreciation of a problem, developing a strategy and experimenting, and re-appreciation of the problem, reflection helps coaches to improve their practical application. Though it was not the purpose of this thesis, reflecting on some of the challenges and solutions of integrating strength and conditioning into school curriculum may help other practitioners that face similar obstacles. One major challenge was the initial lack of resources and facilities to conduct the training sessions. There was only one regular sized gymnasium and an ill-equipped weight room converted from a pre-fabricated classroom. Another challenge was the school's one-hour class periods and two-week rotating timetable, which made organizing training and data collection difficult. Finally, the variability in the participants' strength, coordination and maturation made it challenging to ensure the optimal stimulus was given to everyone.

With a heroic effort from everyone involved, solutions were found for each of the challenges presented. The caretaker bought some wood for three lifting platforms and crafted some blocks (about 30 cm tall), which were used for supporting the barbell just below the knee or stacked to provide feedback for appropriate squat depth. The school was able to secure a grant for an additional barbell, rubber bumper plates, and wooden dowel rods – essential tools for effective progression and implementation of weightlifting exercises. The addition of three portable squat stands to the three existing multi-purpose racks totaled six work stations – three on each side of the gym. Dumbbells, kettlebells, and medicine balls on racks against the wall on one end and a soft, stackable, plyometric box with plastic hurdles against the wall on the other end. The gym was redesigned for functionality in a school setting. During a week of the school holidays, some students even came in to help paint the school colors – navy and gold - over the light blue walls of the gym. The physical education teachers were often accommodating to the athletic development program, allowing the participants access to the gymnasium for speed and plyometric training when it was raining outside for much of the New Zealand winter. Due to the rotating A and B week schedule, data collection was done prior to the last week of the term to ensure participants were completing the pre-, mid-, and post-testing sessions during the same class period at each time point. Although this ensured continuity between time points, it essentially took away a week of training each term. Lastly, a beginner, intermediate, and advanced level exercise was provided for all the resistance training and weightlifting exercises prescribed to ensure technical competency and appropriate challenge was delivered based on a participant's skill level. This approach was published in Chapter 3 and had previously been used by Meylan et al. [128] as a method to manage groups of athletes that vary greatly in maturation and technical competency. These challenges required reflective practice to draw upon previous theoretical and scientific knowledge and translate it into practice through integration within the school curriculum.

Limitations

There were several limitations of the thesis, due in part to the unique integration within a school curriculum. One limitation in Chapter 5 was the lack of a control group, which was excluded for several reasons. Participants in the training groups were recruited from a secondary school athletic development program, which was comprised of the school's top year nine and ten athletes. Based on the school's selection process, which is primarily a series of physical tests, it is expected that the students chosen would outperform students not chosen for the program in motor skill tasks such as running and jumping. The primary purpose of Chapter 5 was to compare CRT to a program where some of the CRT training was replaced with WL, providing a comparison of the influence of mode of training while training dose was kept similar between groups. Furthermore, several youth resistance training studies have compared the effects of different programs without the inclusion of a control group [248, 249]. Even still, training groups in Chapter 5 improved jump and sprint performance similarly to previous studies [206-209] and when converted to annual rates, improvements were well above those reported for athletes in an athletic development program who did not engage in resistance training [210]. Thus, comparing changes in motor skill performance between different resistance training programs without the use of a control group was warranted.

In Chapter 6, a control group was included to compare movement competency development in physical education to the addition of CRT or CRT&WL. The results from the cross-sectional study in Chapter 4 demonstrated that overall movement competency and motor skill performance are independent qualities and baseline testing confirmed that there was little difference between the training and control groups for most of the RTSB movements. These findings suggested that it would be worthwhile to examine the development of movement competency of participants who did and did not participant in an athlete development program. This approach is supported by existing athletic development models that highlight the importance of movement competency for the successful long-term physical development of all children [3]. Given that the aim of Chapter 5 was to examine the development of motor skills that contribute to success in many sports, the chapter is focused more on youth who have chosen to follow a performance pathway through sport.

There were several limitations to the training intervention that were governed by the school curriculum. For example, the training program only differed by two or three movements per session, which may not have been enough to differentiate the effects of resistance training with or without weightlifting movements. The intervention was implemented within the school curriculum for two 55 to 60-minute training sessions per week, which has shown to be effective for improving athleticism [207, 208]. However, half of this time was spent either outside or in a gymnasium doing the same plyometric, speed, and agility exercises for both groups, whereas the other half of the time was spent in the weight room doing different resistance training programs. A resistance training program that focused exclusively on strength training or weightlifting for the whole duration of class may have been able to better differentiate training adaptations, but the inclusion of plyometric, speed, and agility components represent a more holistic approach common to many high school athletic development programs and therefore was used for this thesis. It is also worth noting that over the course of the year the program did provide sufficient time for participants in the WL group to become technically competent in a range of WL derivatives, in addition to improving their physical fitness.

In addition to the similarity between each group's training program, the duration of the intervention was a limitation. The CRT group performed simpler exercises compared to the CRT&WL group, which allowed for intensity to be progressed relatively quickly. However, the weightlifting exercises are relatively complex and require more time to be devoted to learning weightlifting skills, so much of the intervention involved low loads and pauses at different positions to ensure technical competency. Since the intervention only included one year of training, it is difficult to determine whether weightlifting training would provide greater benefits once technique as proficient and intensity can be increased. Given the recommendation of LTAD models to incorporate a variety of activities to optimally development motor skills, it is still prudent to teach youth weightlifting exercises.

Studies using invasive or lab-based protocols may provide valuable mechanistic knowledge regarding training adaptation, but those approaches are not practical for coaches working with large groups or less-resourced settings. To make our research more applied, many of the dependent variables were obtained from relatively simple field tests that require relatively inexpensive equipment. This approach was used to provide practitioners meaningful data from familiar and easily accessible testing protocols and allow a reasonably large sample of participants to be included in the research. While our results provide a general overview of how different types of training affect gross measures of different fitness components, the underlying mechanisms responsible for the overall improvement in motor skill performance can only be speculated.

Future research directions

The limitations presented in the previous section can help inform future research directions to further our understanding of how weightlifting influences the athleticism of young male athletes. First, research using an intervention with more pronounced differences in exercise or overall exposure to weightlifting movements can help differentiate improvements between CRT and CRT&WL. Creating larger differences in the training stimulus could be done by increasing the number of weightlifting exercises that a CRT&WL group follows or by increasing the number of training sessions per week. For example, Chaouachi et al. [19] used four different exercises to compare weightlifting and traditional strength training in prepubertal athletes and Channell and Barfield [20] used three sessions per week in their intervention with postpubertal athletes. Future research could use a combination of these approaches to further elucidate the benefits specific to weightlifting exercises.

This thesis found significant improvements in performance of field tests commonly used in athletic development programs. Chapters 4, 5, and 6 provide insight into the relationships and development of a broad range of skills common to many sports, such as sprinting and jumping. However, since the aim of the thesis was to measure the effects of a holistic athletic development program, the mechanisms responsible for the physiological adaptations remain unclear. Future research utilizing weightlifting movements in youth athletes should explore the physiological mechanisms responsible for improvements in individual fitness components separately in greater detail to develop practitioners' understanding of how the body adapts to training. Specifically, research focused on structural (pennation angle, tendon thickness, stiffness) and neural (motor unit recruitment, coordination, co-contraction) after weightlifting training may give deeper insight into the design and assist practitioners with the implementation of weightlifting training.

Chapters 5 and 6 demonstrated the improvements in motor skill performance and landing kinematics adolescents can achieve after one year of an introductory resistance training program. The trend of improvements in Chapter 5 also indicated that motor skill performance improved more as training age and intensity increased, which is supported by previous meta-analyses that demonstrate loads of 80-89% of 1RM are best for increasing muscular strength, speed, and agility performance. However, due to the complexity of the weightlifting exercises, the CRT&WL group was often lifting lesser loads than the CRT participants in certain movements. Nevertheless, both groups experienced similar performance gains after the introductory training program. Previous research has shown greater gains made after a second year of training compared to the first year [205], so given another year of weightlifting training with proficient technique, the improvements from CRT&WL may be larger when compared to CRT. Therefore, future research should monitor participants for a longer period to examine any additional benefits of weightlifting once technical competency is achieved after a year-long progression. From a long-term development perspective, it seems prudent to spend up to a year learning technique of weightlifting movements with a relatively low load, especially if greater loads on weightlifting exercises eventually lead to more pronounced power adaptations compared to CRT. Chapters 5 and 6 demonstrate that improvements in motor skill performance and movement competency occur alongside the mastery of weightlifting technique with relatively light loads, so the time taken to learn these movements is not necessarily wasted. Given the focus on a long-term approach for optimal physical development, coaches should not choose to incorporate simpler exercises on the basis that they can be loaded sooner. Whether preparing a child for a higher level of competition or a life of recreational activity, coaches should aim to provide as many different tools for an athlete's toolbox of movements.

References

1. Côté, J., *The influence of the family in the development of talent in sport.* Sport Psychol, 1999. **13**(4): p. 395-417.
2. Balyi, I. and A. Hamilton, *Long-term athlete development-Trainability in childhood and adolescence-Windows of opportunity- Optimal trainability.* National Coaching Institute British Columbia, Canada & Advanced Training and Performance Ltd. Victoria, B.C., Canada, 2004. **16**(1): p. 4-9.
3. Lloyd, R.S. and J.L. Oliver, *The youth physical development model: A new approach to long-term athletic development.* Strength Cond J, 2012. **34**(3): p. 61-72.
4. Granacher, U., et al., *Effects of resistance training in youth athletes on muscular fitness and athletic performance: A conceptual model for long-term athlete development.* Front Physiol, 2016. **7**(164): p. 1-14.
5. Lloyd, R.S., et al., *Long-term athletic development and its application to youth weightlifting.* Strength Cond J, 2012. **34**(4): p. 55-66.
6. Lloyd, R.S., R.W. Meyers, and J.L. Oliver, *The natural development and trainability of plyometric ability during childhood.* Strength Cond J, 2011. **33**(2): p. 23-32.
7. Meylan, C.M., et al., *An evidence-based model of power development in youth soccer.* Int J Sports Sci Coach, 2014. **9**(5): p. 1241-1264.
8. Oliver, J.L., R.S. Lloyd, and M.C. Rumpf, *Developing speed throughout childhood and adolescence.* Strength Cond J, 2013. **35**(3): p. 42-48.
9. Lloyd, R.S., et al., *Considerations for the development of agility during childhood and adolescence.* Strength Cond J, 2013. **35**(3): p. 2-11.
10. Harrison, C.B., et al., *Development of aerobic fitness in young team sport athletes.* Sports Med, 2015. **45**(7): p. 969-983.
11. Lesinski, M., O. Prieske, and U. Granacher, *Effects and dose-response relationships of resistance training on physical performance in youth athletes: A systematic review and meta-analysis.* Br J Sports Med, 2016. **50**(12): p. 781-795.
12. McGladrey, B.W., et al., *High school physical educators' and sport coaches' knowledge of resistance training principles and methods.* J Strength Cond Res, 2014. **28**(5): p. 1433-1442.
13. Jeffreys, I., *Quadrennial planning for the high school athlete.* Strength Cond J, 2008. **30**(3): p. 74-83.
14. Lloyd, R.S., et al., *National Strength and Conditioning Association position statement on long-term athletic development.* J Strength Cond Res, 2016. **30**(6): p. 1491-1509.
15. Behringer, M., et al., *Effects of resistance training in children and adolescents: A meta-analysis.* Pediatrics, 2010. **126**(5): p. e1199-1210.
16. Behringer, M., et al., *Effects of strength training on motor performance skills in children and adolescents: A meta-analysis.* Pediatr Exerc Sci, 2011. **23**(2): p. 186-206.
17. Radnor, J.M., R.S. Lloyd, and J.L. Oliver, *Individual response to different forms of resistance training in school-aged boys.* J Strength Cond Res, 2017. **31**(3): p. 787-797.

18. Lloyd, R.S., et al., *Changes in sprint and jump performances after traditional, plyometric, and combined resistance training in male youth pre- and post-peak height velocity*. J Strength Cond Res, 2016. **30**(5): p. 1239-1247.
19. Chaouachi, A., et al., *Olympic weightlifting and plyometric training with children provides similar or greater performance improvements than traditional resistance training.* J Strength Cond Res, 2014. **28**(6): p. 1483-1496.
20. Channell, B.T. and J. Barfield, *Effect of olympic and traditional resistance training on vertical jump improvement in high school boys.* J Strength Cond Res, 2008. **22**(5): p. 1522-1527.
21. Byrd, R., et al., *Young weightlifters' performance across time.* Sports Biomech, 2003. **2**(1): p. 133-40.
22. Bult, H., M. Barendrecht, and I. Tak, *Injury risk and injury burden are related to age group and peak height velocity among talented male youth soccer players.* Orthop J Sports Med, 2018. **6**(12): p. 1-10.
23. Read, P.J., et al., *Assessment of injury risk factors in male youth soccer players.* Strength Cond J, 2016. **38**(1): p. 12-21.
24. Emery, C.A., et al., *Neuromuscular training injury prevention strategies in youth sport: A systematic review and meta-analysis.* Br J Sports Med, 2015. **49**(13): p. 865-870.
25. Behringer, M., et al., *Effects of weight-bearing activities on bone mineral content and density in children and adolescents: A meta-analysis.* J Bone Miner Res, 2014. **29**(2): p. 467-478.
26. Ebada, K.A., *The effect of a training program on the development of the maximal strength for weightlifting beginner's performance.* Selcuk University Journal of Physical Education and Sport Science, 2011. **13**(3): p. 281-290.
27. Gagné, F., *Constructs and models pertaining to exceptional human abilities*, in *International handbook of research and development of giftedness and talent,* K.A. Heller, F.J. Mönks, and A.H. Passow, Editors. 1993, Pergamon Press: Elmsford, NY, US. p. 69-87.
28. Lloyd, R.S., et al., *Long-term athletic development, part 1: A pathway for all youth.* J Strength Cond Res 2015. **29**(5): p. 1439-1450.
29. DiFiori, J.P., et al., *Overuse injuries and burnout in youth sports: a position statement from the American Medical Society for Sports Medicine.* Br J Sports Med, 2014. **48**(4): p. 287-288.
30. Goodway, J.D. and L.E. Robinson, *Developmental trajectories in early sport specialization: A case for early sampling from a physical growth and motor development perspective.* Kinesiol Rev, 2015. **4**(3): p. 267-278.
31. Jayanthi, N.A. and L.R. Dugas, *The risks of sports specialization in the adolescent female athlete.* Strength Cond J, 2017. **39**(2): p. 20-26.
32. Valovich McLeod, T.C., et al., *National Athletic Trainers' Association position statement: Prevention of pediatric overuse injuries.* J Athl Train, 2011. **46**(2): p. 206-220.
33. McKeown, I. and N. Ball, *Current practices of long term athlete development of junior athletes in high performance sport environments.* J Aust Strength Cond, 2013. **21**(1): p. 4-12.

34. Abbassi, V., *Growth and normal puberty.* Pediatrics, 1998. **102**(3): p. 507-511.
35. Viru, A., et al., *Critical periods in the development of performance capacity during childhood and adolescence.* Eur J Phys Educ, 1999. **4**(1): p. 75-119.
36. Balyi, I., *Sport system building and long-term athlete development in British Columbia.* Canada: SportsMed BC, 2001. **8**(1): p. 22-28.
37. Ford, P., et al., *The long-term athlete development model: Physiological evidence and application.* J Sports Sci, 2011. **29**(4): p. 389-402.
38. Bailey, R., et al., *Participant development in sport: An academic review*. Sports Coach UK, 2010. **4**: p. 1-134.
39. Read, P.J., et al., *The scientific foundations and associated injury risks of early soccer specialisation.* J Sports Sci, 2016. **34**(24): p. 2295-2302.
40. Ericsson, K.A., R.T. Krampe, and C. Tesch-Romer, *The role of deliberate practice in the acquisition of expert performance.* Psychol Rev, 1993. **100**(3): p. 363-406.
41. Ericsson, K.A., *Training history, deliberate practice and elite sports performance: an analysis in response to Tucker and Collins review-what makes champions?* Br J Sports Med, 2013. **47**(9): p. 533-535.
42. Baker, J. and B. Young, *20 years later: Deliberate practice and the development of expertise in sport.* Int Rev Sport Exerc Psychol, 2014. **7**(1): p. 135-157.
43. Fransen, J., et al., *Differences in physical fitness and gross motor coordination in boys aged 6–12 years specializing in one versus sampling more than one sport.* J Sports Sci, 2012. **30**(4): p. 379-386.
44. Moesch, K., et al., *Late specialization: The key to success in centimeters, grams, or seconds (cgs) sports.* Scand J Med Sci Sports, 2011. **21**(6): p. 1-9.
45. Lloyd, R.S., et al., *Chronological age vs. biological maturation: Implications for exercise programming in youth.* J Strength Cond Res, 2014. **28**(5): p. 1454-1464.
46. Sander, A., et al., *Influence of a 2-year strength training programme on power performance in elite youth soccer players.* Eur J Sport Sci, 2013. **13**(5): p. 445-451.
47. Keiner, M., et al., *Strength performance in youth: Trainability of adolescents and children in the back and front squats.* J Strength Cond Res, 2013. **27**(2): p. 357-362.
48. Keiner, M., et al., *Long-term strength training effects on change-of-direction sprint performance.* J Strength Cond Res, 2014. **28**(1): p. 223-231.
49. Lloyd, R.S., et al., *Position statement on youth resistance training: The 2014 international consensus.* Br J Sports Med, 2014. **48**(7): p. 498-505.
50. Faigenbaum, A.D., et al., *Youth resistance training: Updated position statement paper from the National Strength and Conditioning Association.* J Strength Cond Res, 2009. **23**(5): p. S60-S79.
51. Stratton, G., et al., *BASES position statement on guidelines for resistance exercise in young people.* J Sports Sci, 2004. **22**(4): p. 383-390.
52. Lloyd, R.S., et al., *UKSCA position statement: Youth resistance training.* Professional Strength and Conditioning, 2012. **26**: p. 26-39.
53. Baker, D., et al., *Resistance training for children and youth: A position statement from the Australian Strength and Conditioning Association.* 2007. **12**: p. 1-80.
54. Behm, D.G., et al., *Effectiveness of traditional strength vs. power training on muscle strength, power and speed with youth: A systematic review and meta-analysis.* Front Physiol, 2017. **8**: p. 423.

55. Hackett, D., et al., *Olympic weightlifting training improves vertical jump height in sportspeople: A systematic review with meta-analysis.* Br J Sports Med, 2016. **50**(14): p. 865-872.
56. Hamill, B.P., *Relative safety of weightlifting and weight training.* J Strength Cond Res, 1994. **8**(1): p. 53-57.
57. USA Weightlifting. *USAW Athlete Development Model*. 2016; Available from: http://www.teamusa.org/USA-Weightlifting/ADM-Videos.
58. Canadian Weightlifting Federation Halterophile Canadienne. *Transition Phase: Long-Term Athlete Development*. 2017 [cited 2017 30 May 2017]; Available from: http://www.halterophiliecanada.ca/wp-content/uploads/2016/11/CWF_Book-v9_fev2012_Reduit1.pdf.
59. Higgs, C., et al., *Developing physical literacy: A guide for parents of children ages 0 to 12.* Vancouver, BC: Canadian Sports Centres, 2008.
60. Bazyler, C.D., et al., *Changes in muscle architecture, explosive ability, and track and field throwing performance throughout a competitive season and following a taper.* J Strength Cond Res, 2017. **31**(10): p. 2785-2793.
61. Read, P.J., et al., *Relationships between field-based measures of strength and power and golf club head speed.* J Strength Cond Res 2013. **27**(10): p. 2708-2713.
62. DiStefano, L.J., et al., *The effects of an injury prevention program on landing biomechanics over time.* Am J Sports Med, 2016. **44**(3): p. 767-776.
63. Till, K., S. Scantlebury, and B. Jones, *Anthropometric and physical qualities of elite male youth rugby league players.* Sports Med, 2017. **47**(11): p. 2171-2186.
64. Kobal, R., et al., *Physical performance of Brazilian rugby players From different age categories and competitive levels.* J Strength Cond Res, 2016. **30**(9): p. 2433-2439.
65. Hori, N., et al., *Does performance of hang power clean differentiate performance of jumping, sprinting, and changing of direction?* J Strength Cond Res, 2008. **22**(2): p. 412-8.
66. Townsend, J.R., et al., *Isometric mid-thigh pull performance is associated with athletic performance and sprinting kinetics In division I men and women's basketball players.* J Strength Cond Res, 2017. **Published ahead of print**.
67. Moran, J., et al., *Variation in responses to sprint training in male youth athletes: A meta-analysis.* Int J Sports Med, 2017. **38**(1): p. 1-11.
68. Meyers, R.W., et al., *New insights into the development of maximal sprint speed in male youth.* Strength Cond J, 2017. **39**(2): p. 2-10.
69. Tonson, A., et al., *Effect of Maturation on the Relationship between Muscle Size and Force Production.* Medicine & Science in Sports & Exercise, 2008. **40**(5): p. 918-925.
70. Rumpf, M.C., et al., *Effect of different training methods on running sprint times in male youth.* Pediatr Exerc Sci, 2012. **24**(2): p. 170-186.
71. Rumpf, M.C., et al., *The effect of resisted sprint training on maximum sprint kinetics and kinematics in youth.* Eur J Sport Sci, 2015. **15**(5): p. 374-381.
72. Cattuzzo, M.T., et al., *Motor competence and health related physical fitness in youth: A systematic review.* J Sci Med Sport, 2016. **19**(2): p. 123-129.

73. Okely, A.D., M.L. Booth, and J.W. Patterson, *Relationship of physical activity to fundamental movement skills among adolescents.* Med Sci Sports Exerc, 2001. **33**(11): p. 1899-1904.
74. Sheppard, J.M. and W.B. Young, *Agility literature review: Classifications, training and testing.* J Sports Sci, 2006. **24**(9): p. 919-932.
75. Bedoya, A.A., M.R. Miltenberger, and R.M. Lopez, *Plyometric training effects on performance in youth soccer athletes: A systematic review.* J Strength Cond Res, 2015. **29**(8): p. 2351-2360.
76. Asadi, A., et al., *Influence of maturation stage on agility performance gains after plyometric training: A systematic review and meta-analysis.* J Strength Cond Res, 2017. **31**(9): p. 2609-2617.
77. Thomas, C., et al., *A comparison of isometric mid-thigh pull strength, vertical jump, sprint speed, and change of direction speed in academy netball players.* Int J Sports Physiol Perform, 2017. **7**(12): p. 916-921.
78. Lloyd, R.S., et al., *Relationships between functional movement screen scores, maturation and physical performance in young soccer players.* J Sports Sci, 2015. **33**(1): p. 11-19.
79. Hopper, A., et al., *Neuromuscular training improves movement competency and physical performance measures in 11–13-year-old female netball athletes.* J Strength Cond Res, 2017. **31**(5): p. 1165-1176.
80. Quatman-Yates, C.C., et al., *A systematic review of sensorimotor function during adolescence: a developmental stage of increased motor awkwardness?* Br J Sports Med, 2012. **46**(9): p. 649-655.
81. Strøyer, J., L. Hansen, and K. Klausen, *Physiological profile and activity pattern of young soccer players during match play.* Med Sci Sports Exerc, 2004. **36**(1): p. 168-174.
82. Tomlin, D.L. and H.A. Wenger, *The relationship between aerobic fitness and recovery from high intensity intermittent exercise.* Sports Med, 2001. **31**(1): p. 1-11.
83. Chamari, K., et al., *Endurance training and testing with the ball in young elite soccer players.* Br J Sports Med, 2005. **39**(1): p. 24-28.
84. Harrison, C.B., et al., *Small-sided games for young athletes: is game specificity influential?* J Sports Sci, 2014. **32**(4): p. 336-344.
85. Armstrong, N. and A.R. Barker, *Endurance Training and Elite Young Athletes*, in *The Elite Young Athlete*, N. Armstrong and A. McManus, Editors. 2011, Karger: Basel. p. 59-83.
86. Baquet, G., et al., *Effects of high intensity intermittent training on peak VO2 in prepubertal children.* Int J Sports Med, 2002. **23**(6): p. 439-444.
87. Faigenbaum, A.D., et al., *Preliminary evaluation of an after-school resistance training program for improving physical fitness in middle school-age boys.* Percept Mot Skills, 2007. **104**(2): p. 407-415.
88. Faigenbaum, A.D., et al., *The effects of different resistance training protocols on muscular strength and endurance development in children.* Pediatrics, 1999. **104**(1): p. 1-7.
89. Ratel, S. and A.J. Blazevich, *Are prepubertal children metabolically comparable to well-trained adult endurance athletes?* Sports Med, 2017. **47**(8): p. 1477-1485.

90. Schranz, N., G. Tomkinson, and T. Olds, *What is the effect of resistance training on the strength, body composition and psychosocial status of overweight and obese children and adolescents? A systematic review and meta-analysis.* Sports Med, 2013. **43**(9): p. 893-907.
91. Moliner-Urdiales, D., et al., *Secular trends in health-related physical fitness in Spanish adolescents: The AVENA and HELENA Studies.* J Sci Med Sport, 2010. **13**(6): p. 584-588.
92. Runhaar, J., et al., *Motor fitness in Dutch youth: Differences over a 26-year period (1980–2006).* J Sports Sci Med, 2010. **13**(3): p. 323-328.
93. Hardy, L.L., et al., *Thirteen-year trends in child and adolescent fundamental movement skills: 1997-2010.* Med Sci Sports Exerc, 2013. **45**(10): p. 1965-1970.
94. Dollman, J., K. Norton, and L. Norton, *Evidence for secular trends in children's physical activity behaviour.* Br J Sports Med, 2005. **39**(12): p. 892-897.
95. Michaud, P., A. Renaud, and F. Narring, *Sports activities related to injuries? A survey among 9–19 year olds in Switzerland.* Inj Prev, 2001. **7**(1): p. 41-45.
96. Kennedy, S.G., et al., *Implementing resistance training in secondary schools: A cluster RCT.* Med Sci Sports Exerc, 2018. **50**(1): p. 62-72.
97. World Health Organization, *Global Recommendations on Physical Activity for Health*. 2011.
98. Jackowski, S.A., et al., *A longitudinal study of bone area, content, density, and strength development at the radius and tibia in children 4-12 years of age exposed to recreational gymnastics.* Osteoporos Int, 2015. **26**(6): p. 1677-1690.
99. Conroy, B.P., et al., *Bone mineral density in elite junior Olympic weightlifters.* Med Sci Sports Exerc, 1993. **25**(10): p. 1103-1109.
100. American Academy of Pediatrics, *Weight training and weightlifting: Information for the pediatrician.* Phys Sportsmed, 1983. **11**(3): p. 157-161.
101. Faigenbaum, A.D. and G.D. Myer, *Resistance training among young athletes: Safety, efficacy and injury prevention effects.* Br J Sports Med, 2010. **44**(1): p. 56-63.
102. Palmer-Green, D.S., et al., *Training activities and injuries in English youth academy and schools rugby union.* Am J Sports Med, 2015. **43**(2): p. 475-481.
103. Faigenbaum, A.D. and L. Meadors, *A coach's dozen: An update on building healthy, strong, and resilient young athletes.* Strength Cond J, 2017. **39**(2): p. 27-33.
104. Mandigo, J., et al., *Physical literacy for educators.* Physical & Health Education Journal, 2009. **75**(3): p. 27-30.
105. Haff, G.G., *Periodization strategies for youth development*, in *Strength and Conditioning for Young Athletes: Science and Application*, R.S. Lloyd and J.L. Oliver, Editors. 2013, Routledge: Oxford, UK. p. 149-168.
106. Harries, S.K., D.R. Lubans, and R. Callister, *Resistance training to improve power and sports performance in adolescent athletes: A systematic review and meta-analysis.* J Sports Sci Med, 2012. **15**(6): p. 532-540.
107. Haff, G.G. and E.E. Haff, *Training integration and periodization*, in *NSCA's Guide to Program Design*, J. Hoffman, Editor. 2012, Human Kinetics: Champaign, IL. p. 209-254.
108. Issurin, V.B., *Block periodization versus traditional training theory: A review.* J Sports Med Phys Fitness, 2008. **48**(1): p. 65-75.

109. Issurin, V.B., *New horizons for the methodology and physiology of training periodization.* Sports Med, 2010. **40**(3): p. 189-206.
110. Poliquin, C., *Football: Five steps to increasing the effectiveness of your strength training program.* Strength Cond J, 1988. **10**(3): p. 34-39.
111. Harries, S.K., D.R. Lubans, and R. Callister, *Systematic review and meta-analysis of linear and undulating periodized resistance training programs on muscular strength.* J Strength Cond Res, 2015. **29**(4): p. 1113-1125.
112. Harries, S.K., et al., *Effects of 12-weeks resistance training on sprint and jump performance in competitive adolescent rugby union players.* J Strength Cond Res, 2018. **32**(12): p. 2762-2769.
113. Painter, K.B., et al., *Strength gains: Block versus daily undulating periodization weight training among track and field athletes.* Int J Sports Physiol Perform, 2012. **7**(2): p. 161-169.
114. Haff, G.G., *Periodization for tactical populations*, in *NSCA's Essentials of Tactical Strength and Conditioning*, B.A. Alvar, K. Sell, and P.A. Deuster, Editors. 2017, Human Kinetics: Champaign, IL. p. 181-206.
115. Rivière, M., et al., *Variable resistance training promotes greater strength and power adaptations than traditional resistance training in elite youth rugby league players.* J Strength Cond Res, 2017. **31**(4): p. 947-955.
116. Seefeldt, V., *Developmental motor patterns: Implications for elementary school physical education.*, in *Psychology of Motor Behavior and Sport*, C.H. Nadeau, et al., Editors. 1980, Human Kinetics: Champaign, IL. p. 314-323.
117. Parsonage, J.R., et al., *Assessment of conditioning-specific movement tasks and physical fitness measures in talent identified under 16-year-old rugby union players.* J Strength Cond Res, 2014. **28**(6): p. 1497-1506.
118. McKay, D., C. Broderick, and K. Steinbeck, *The adolescent athlete: A developmental approach to injury risk.* Pediatr Exerc Sci, 2016. **28**(4): p. 488-500.
119. Schmikli, S.L., et al., *Can we detect non-functional overreaching in young elite soccer players and middle-long distance runners using field performance tests?* Br J Sports Med, 2011. **45**(8): p. 631-636.
120. Mirwald, R.L., et al., *An assessment of maturity from anthropometric measurements.* Med Sci Sports Exerc, 2002. **34**(4): p. 689-694.
121. Khamis, H.J. and A.F. Roche, *Predicting adult stature without using skeletal age: The Khamis-Roche method.* Pediatrics, 1994. **94**(4): p. 504-507.
122. Bergeron, M.F., et al., *International Olympic Committee consensus statement on youth athletic development.* Br J Sports Med, 2015. **49**(13): p. 843-851.
123. Duehring, M.D., C.R. Feldmann, and W.P. Ebben, *Strength and conditioning practices of United States high school strength and conditioning coaches.* J Strength Cond Res, 2009. **23**(8): p. 2188-2203.
124. Moody, J.A., et al., *Motor skill development in youths*, in *Strength and Conditioning for Young Athletes: Practice and Application*, R.S. Lloyd and J. Oliver, Editors. 2013, Routledge: New York, NY. p. 49-65.
125. Harris, G.R., et al., *Short-term performance effects of high power, high force, or combined weight-training methods.* J Strength Cond Res, 2000. **14**(1): p. 14-20.

126. Haff, G.G. and S. Nimphius, *Training principles for power.* Strength Cond J, 2012. **34**(6): p. 2-12.
127. Zebis, M.K., et al., *Effects of evidence-based prevention training on neuromuscular and biomechanical risk factors for ACL injury in adolescent female athletes: A randomised controlled trial.* Br J Sports Med, 2016. **50**(9): p. 552-557.
128. Meylan, C.M., et al., *The effect of maturation on adaptations to strength training and detraining in 11–15-year-olds.* Scand J Med Sci Sports, 2014. **24**(3): p. e156-e164.
129. Kritz, M.F. and J.B. Cronin, *Static posture assessment screen of athletes: Benefits and considerations.* Strength Cond J, 2008. **30**(5): p. 18-27.
130. Kritz, M.F., J.B. Cronin, and P.A. Hume, *The bodyweight squat: A movement screen for the squat pattern.* Strength Cond J, 2009. **31**(1): p. 76-85.
131. Kritz, M.F., J.B. Cronin, and P.A. Hume, *Using the body weight forward lunge to screen an athlete's lunge pattern.* Strength Cond J, 2009. **31**(6): p. 15-24.
132. Kritz, M.F., J.B. Cronin, and P.A. Hume, *Screening the upper-body push and pull patterns using body weight exercises.* Strength Cond J, 2010. **32**(3): p. 72-82.
133. Lubans, D.R., et al., *Development, test-retest reliability, and construct validity of the resistance training skills battery.* J Strength Cond Res, 2014. **28**(5): p. 1373-1380.
134. Myer, G.D., et al., *The back squat: A proposed assessment of functional deficits and technical factors that limit performance.* Strength Cond J, 2014. **36**(6): p. 4-27.
135. Coutts, A.J., A.J. Murphy, and B.J. Dascombe, *Effect of direct supervision of a strength coach on measures of muscular strength and power in young rugby league players.* J Strength Cond Res, 2004. **18**(2): p. 316-323.
136. Myer, G.D., et al., *Youth versus adult "weightlifting" injuries presenting to United States emergency rooms: Accidental versus nonaccidental injury mechanisms.* J Strength Cond Res, 2009. **23**(7): p. 2054-2060.
137. Gould, J.H. and A.R. DeJong, *Injuries to children involving home exercise equipment.* Arch Pediatr Adolesc Med, 1994. **148**(10): p. 1107-1109.
138. Williams, A.M. and N.J. Hodges, *Practice, instruction and skill acquisition in soccer: Challenging tradition.* J Sports Sci, 2005. **23**(6): p. 637-650.
139. Jaakkola, T., et al., *Students' perceptions of motivational climate and enjoyment in Finnish physical education: A latent profile analysis.* J Sports Sci Med, 2015. **14**(3): p. 477-483.
140. Halperin, I., et al., *Autonomy: A missing ingredient of a successful program?* Strength Cond J, 2018. **40**(4): p. 18-25.
141. Chamberlin, J.M., M.D. Fry, and S. Iwasaki, *High school athletes' perceptions of the motivational climate in their off-season training programs.* J Strength Cond Res, 2017. **31**(3): p. 736-742.
142. Christodoulidis, T., A. Papaioannou, and N. Digelidis, *Motivational climate and attitudes towards exercise in Greek senior high school: A year-long intervention.* Eur J Sport Sci, 2001. **1**(4): p. 1-12.
143. Kushner, A.M., et al., *The back squat part 2: Targeted training techniques to correct functional deficits and technical factors that limit performance.* Strength Cond J, 2015. **37**(2): p. 13.
144. Verhoeff, W.J., *A Constraints-led Approach to Acquiring the Power Clean (Thesis)*. 2016, Auckland University of Technology.

145. Jeraj, D., et al., *How do gymnastics coaches provide movement feedback in training?* Int J Sports Sci Coach, 2015. **10**(6): p. 1015-1024.
146. Marchant, D., *Attentional focusing instructions and force production.* Front Psychol, 2011. **1**(210).
147. Halperin, I., et al., *The effects of attentional focusing instructions on force production during the isometric midthigh pull.* J Strength Cond Res, 2016. **30**(4): p. 919-923.
148. Porter, J.M., et al., *Standing long-jump performance is enhanced when using an external focus of attention.* J Strength Cond Res, 2010. **24**(7): p. 1746-1750.
149. Porter, J.M., et al., *Adopting an external focus of attention improves sprinting performance in low-skilled sprinters.* J Strength Cond Res, 2015. **29**(4): p. 947-953.
150. Winkelman, N.C., *Attentional focus and cueing for speed development.* Strength Cond J, 2018. **40**(1): p. 13-25.
151. Rucci, J.A. and P.D. Tomporowski, *Three types of kinematic feedback and the execution of the hang power clean.* J Strength Cond Res, 2010. **24**(3): p. 771-778.
152. Mulqueen, D., *Using Video Modeling and Video Feedback to Improve Olympic Weightlifting Technique (Thesis)*. 2014, University of South Florida.
153. Napoles, V.V., *The Effects of Expert Video Modeling, Video Self-Monitoring, and Video Feedback on Improving Olympic Weightlifting Form (Thesis)*. 2017, The Chicago School of Professional Psychology.
154. Winchester, J.B., J.M. Porter, and J.M. McBride, *Changes in bar path kinematics and kinetics through use of summary feedback in power snatch training.* J Strength Cond Res, 2009. **23**(2): p. 444-454.
155. Winchester, J.B., et al., *Changes in bar-path kinematics and kinetics after power-clean training.* J Strength Cond Res, 2005. **19**(1): p. 177-183.
156. Pichardo, A.W., et al., *Integrating models of long-term athletic development to maximize the physical development of youth.* Int J Sports Sci Coach, 2018. **13**(6): p. 1189-1199.
157. Malina, R.M., C. Bouchard, and O. Bar-Or, *Growth, Maturation, and Physical Activity*. 2004, Champagne, IL: Human Kinetics.
158. Philippaerts, R.M., et al., *The relationship between peak height velocity and physical performance in youth soccer players.* J Sports Sci, 2006. **24**(3): p. 221-230.
159. Cripps, A.J., L.S. Hopper, and C. Joyce, *Maturity, physical ability, technical skill and coaches' perception of semi-elite adolescent Australian footballers.* Pediatr Exerc Sci, 2016. **28**(4): p. 535-541.
160. Cripps, A.J., L.S. Hopper, and C. Joyce, *Coaches' perceptions of long-term potential are biased by maturational variation.* Int J Sports Sci Coach, 2016. **11**(4): p. 478-481.
161. Stone, M.H., *Position statement: Explosive exercises and training.* Strength Cond J, 1993. **15**(3): p. 7-15.
162. Suchomel, T.J., S. Nimphius, and M.H. Stone, *The importance of muscular strength in athletic performance.* Sports Med, 2016. **46**(10): p. 1419-1449.
163. Wing, C.E., A.N. Turner, and C.J. Bishop, *The importance of strength and power on key performance indicators in elite youth soccer.* J Strength Cond Res, 2018. **Published Ahead of Print**.

164. Till, K., et al., *Anthropometric and physical characteristics of English academy rugby league players.* J Strength Cond Res, 2014. **28**(2): p. 319-327.
165. Morris, R.O., et al., *Isometric midthigh pull characteristics in elite youth male soccer players: Comparisons by age and maturity offset.* J Strength Cond Res, 2018. **Published ahead of print**.
166. Emmonds, S., et al., *The influence of age and maturity status on the maximum and explosive strength characteristics of elite youth female soccer players.* Science and Medicine in Football, 2017. **1**(3): p. 209-215.
167. Comfort, P., et al., *Relationships between strength, sprint, and jump performance in well-trained youth soccer players.* J Strength Cond Res, 2014. **28**(1): p. 173-177.
168. Kirkpatrick, J. and P. Comfort, *Strength, power, and speed qualities in English junior elite rugby league players.* J Strength Cond Res, 2013. **27**(9): p. 2414-2419.
169. Meyers, R.W., et al., *Lower limb stiffness and maximal sprint speed in 11-16-year-old boys.* J Strength Cond Res, 2019. **33**(7): p. 1987-1995.
170. Meylan, C.M., et al., *The reliability of jump kinematics and kinetics in children of different maturity status.* J Strength Cond Res, 2012. **26**(4): p. 1015-1026.
171. van der Sluis, A., et al., *Sport injuries aligned to peak height velocity in talented pubertal soccer players.* Int J Sports Med, 2014. **35**(4): p. 351-355.
172. Smith, J.J., et al., *Prevalence and correlates of resistance training skill competence in adolescents.* J Sports Sci, 2018. **36(**11): p. 1241-1249.
173. Okely, A.D., M.L. Booth, and J.W. Patterson, *Relationship of cardiorespiratory endurance to fundamental movement skill proficiency among adolescents.* Pediatr Exerc Sci, 2001. **13**(4): p. 380-391.
174. Von Elm, E., et al., *Strengthening the reporting of observational studies in epidemiology (STROBE) statement: guidelines for reporting observational studies.* J Clin Epidemiol, 2007. **61**: p. 344-349.
175. Comfort, P., et al., *Standardization and methodological considerations for the isometric mid-thigh pull.* Strength Cond J, 2019. **41**(2): p. 57-79.
176. Haff, G.G., et al., *Force-time dependent characteristics of dynamic and isometric muscle actions.* J Strength Cond Res, 1997. **11**(4): p. 269-272.
177. Ashby, B.M. and J.H. Heegaard, *Role of arm motion in the standing long jump.* J Biomech, 2003. **35**(12): p. 1631-1637.
178. Wu, W.-L., et al., *Biomechanical analysis of the standing long jump.* Biomed Eng (Singapore), 2003. **15**(5): p. 186-192.
179. Yanci, J., et al., *Relationships between sprinting, agility, one-and two-leg vertical and horizontal jump in soccer players.* Kinesiology (Zagreb), 2014. **46**(2): p. 194-201.
180. Krustrup, P., et al., *The yo-yo intermittent recovery test: Physiological response, reliability, and validity.* Med Sci Sports Exerc, 2003. **35**(4): p. 697-705.
181. Deprez, D.N., et al., *The Yo-Yo intermittent recovery test level 1 is reliable in young high-level soccer players.* Biol Sport, 2015. **32**(1): p. 65-70.
182. Hopkins, W.G. *A scale of magnitudes for effect statistics*. A New View of Statistics 2006 [cited 2018 14 July]; Available from: http://sportsci.org/resource/stats/effectmag.html.

183. Hopkins, W.G. *Reliability from consecutive pairs of trials*. [Excel spreadsheet] 2000 [cited 2018 May 20]; Available from: http://www.sportsci.org/resource/stats/xrely.xls.
184. Meyers, R.W., et al., *Influence of age, maturity, and body size on the spatiotemporal determinants of maximal sprint speed in boys.* J Strength Cond Res, 2017. **31**(4): p. 1009-1016.
185. Myburgh, G.K., et al., *Maturity-associated variation in functional characteristics of elite youth tennis players*. Pediatr Exerc Sci, 2016. **28**(4): p. 542-552.
186. Rommers, N., et al., *Age and maturity related differences in motor coordination among male elite youth soccer players.* J Sports Sci, 2018. **2**(37): p. 196-203.
187. Emmonds, S., et al., *Importance of physical qualities for speed and change of direction ability in elite female soccer players.* J Strength Cond Res, 2019. **33**(6): p. 1669-1677.
188. Hewett, T.E., G.D. Myer, and K.R. Ford, *Decrease in neuromuscular control about the knee with maturation in female athletes.* J Bone Joint Surg Am, 2004. **86**(8): p. 1601-1608.
189. Quatman, C.E., et al., *Maturation leads to gender differences in landing force and vertical jump performance: a longitudinal study.* Am J Sports Med, 2006. **34**(5): p. 806-813.
190. Wick, K., et al., *Interventions to promote fundamental movement skills in childcare and kindergarten: A systematic review and meta-analysis.* Sports Med, 2017. **47**(10): p. 2045-2068.
191. Morgan, P.J., et al., *Fundamental movement skill interventions in youth: A systematic review and meta-analysis.* Pediatrics, 2013. **132**(5): p. e1361-e1383.
192. Rodriguez-Rosell, D., et al., *Effects of 6 weeks resistance training combined with plyometric and speed exercises on physical performance of pre-peak-height-velocity soccer players.* Int J Sports Physiol Perform, 2016. **11**(2): p. 240-246.
193. Suchomel, T.J., J.P. Lake, and P. Comfort, *Load absorption force-time characteristics following the second pull of weightlifting derivatives.* J Strength Cond Res, 2017. **31**(6): p. 1644-1652.
194. Dos'Santos, T., et al., *Between-session reliability of isometric mid-thigh pull kinetics and maximal power clean performance in male youth soccer players.* J Strength Cond Res, 2018. **32**(12): p. 3364-3372.
195. O'Donnell, S., et al., *The validity and reliability of the GymAware linear position transducer for measuring counter-movement jump performance in female athletes.* Meas Phys Educ Exerc Sci, 2018. **22**(1): p. 101-107.
196. Nuzzo, J.L., J.H. Anning, and J.M. Scharfenberg, *The reliability of three devices ssed for measuring vertical jump height.* J Strength Cond Res, 2011. **25**(9): p. 2580-2590.
197. Faigenbaum, A.D., et al., *Effects of a short-term plyometric and resistance training program on fitness performance in boys age 12 to 15 years.* J Sports Sci Med, 2007. **6**(4): p. 519-525.
198. Hopkins, W.G., et al., *Progressive statistics for studies in sports medicine and exercise science.* Med Sci Sports Exerc, 2009. **41**(1): p. 3.
199. Negra, Y., et al., *Effects of high-velocity resistance training on athletic performance in prepuberal male soccer athletes.* J Strength Cond Res, 2016. **30**(12): p. 3290-3297.

200. Delecluse, C., *Influence of strength training on sprint running performance.* Sports Med, 1997. **24**(3): p. 147-156.
201. Stone, M.H., et al., *Maximum strength-power-performance relationships in collegiate throwers.* J Strength Cond Res, 2003. **17**(4): p. 739-745.
202. Aagaard, P., et al., *Increased rate of force development and neural drive of human skeletal muscle following resistance training.* J Appl Physiol, 2002. **93**(4): p. 1318-1326.
203. Lloyd, R.S., et al., *Age-related differences in the neural regulation of stretch-shortening cycle activities in male youths during maximal and sub-maximal hopping.* J Electromyogr Kinesiol, 2012. **22**(1): p. 37-43.
204. Rumpf, M.C., et al., *Vertical and leg stiffness and stretch-shortening cycle changes across maturation during maximal sprint running.* Hum Mov Sci, 2013. **32**(4): p. 668-676.
205. Till, K., et al., *The influence of training age on the annual development of physical qualities within academy rugby league players.* J Strength Cond Res, 2017. **31**(8): p. 2110-2118.
206. Söhnlein, Q., E. Müller, and T.L. Stöggl, *The effect of 16-week plyometric training on explosive actions in early to mid-puberty elite soccer players.* J Strength Cond Res, 2014. **28**(8): p. 2105-2114.
207. Meylan, C.M. and D. Malatesta, *Effects of in-season plyometric training within soccer practice on explosive actions of young players.* J Strength Cond Res, 2009. **23**(9): p. 2605-2613.
208. Wong, P.-l., K. Chamari, and U. Wisloff, *Effects of 12-week on-field combined strength and power training on physical performance among U-14 young soccer players.* J Strength Cond Res, 2010. **24**(3): p. 644-652.
209. Kotzamanidis, C., *Effect of plyometric training on running performance and vertical jumping in prepubertal boys.* J Strength Cond Res, 2006. **20**(2): p. 441-445.
210. Williams, C.A., J.L. Oliver, and J. Faulkner, *Seasonal monitoring of sprint and jump performance in a soccer youth academy.* Int J Sports Physiol Perform, 2011. **6**(2): p. 264-275.
211. Iuliano-Burns, S., R.L. Mirwald, and D.A. Bailey, *Timing and magnitude of peak height velocity and peak tissue velocities for early, average, and late maturing boys and girls.* Am J Hum Biol, 2001. **13**(1): p. 1-8.
212. Read, P.J., et al., *The effects of maturation on measures of asymmetry during neuromuscular control tests in elite male youth soccer players.* Pedatr Exerc Sci, 2018. **30**(1): p. 168-175.
213. Read, P.J., et al., *Altered landing mechanics are shown by male youth soccer players at different stages of maturation.* Phys Ther Sport, 2018. **33**: p. 48-53.
214. Bishop, C., et al., *Vertical and horizontal asymmetries are related to slower sprinting and jump performance in elite youth female soccer players.* J Strength Cond Res, 2018. **Published Ahead of Print**.
215. Bishop, C., et al., *Jumping asymmetries are associated with speed, change of direction speed, and jump performance in elite academy soccer players.* J Strength Cond Res, 2019. **Published Ahead of Print**.

216. Bailey, C., et al., *Isometric force production symmetry and jumping performance in collegiate athletes.* Journal of Trainology, 2013. **2**(1): p. 1-5.
217. Noyes, F.R., et al., *The drop-jump screening test: Difference in lower limb control by gender and effect of neuromuscular training in female athletes.* Am J Sports Med, 2005. **33**(2): p. 197-207.
218. Barber-Westin, S.D., F.R. Noyes, and M. Galloway, *Jump-land characteristics and muscle strength development in young athletes: A gender comparison of 1140 athletes 9 to 17 years of ge.* Am J Sports Med, 2006. **34**(3): p. 375-384.
219. Barber-Westin, S.D., et al., *Assessment of lower limb neuromuscular control in prepubescent athletes.* Am J Sports Med, 2005. **33**(12): p. 1853-1860.
220. Read, P.J., et al., *Landing kinematics in elite male youth soccer players of different chronologic ages and stages of maturation.* J Athl Train, 2018. **53**(4): p. 372-378.
221. Myer, G.D., K.R. Ford, and T.E. Hewett, *Tuck jump assessment for reducing anterior cruciate ligament injury risk.* Athl Ther Today, 2008. **13**(5): p. 39-44.
222. Klugman, M.F., et al., *Does an in-season only neuromuscular training protocol reduce deficits quantified by the tuck jump assessment?* Clin Sports Med, 2011. **30**(4): p. 825-840.
223. Plisky, P.J., et al., *Star Excursion Balance Test as a predictor of lower extremity injury in high school basketball players.* J Orthop Sports Phys Ther, 2006. **36**(12): p. 911-919.
224. Knapik, J.J., et al., *Preseason strength and flexibility imbalances associated with athletic injuries in female collegiate athletes.* Am J Sports Med, 1991. **19**(1): p. 76-81.
225. Sannicandro, I., et al., *Balance training exercises decrease lower-limb strength asymmetry in young tennis players.* J Sports Sci Med, 2014. **13**(2): p. 397-402.
226. Śliwowski, R., et al., *The effects of individualized resistance strength programs on knee muscular imbalances in junior elite soccer players.* PLOS ONE, 2015. **10**(12): p. 1-14.
227. Reid, D.A., et al., *The inter and intra rater reliability of the Netball Movement Screening Tool.* J Sports Sci Med, 2015. **18**(3): p. 353-357.
228. Cook, G., et al., *Functional movement screening: the use of fundamental movements as an assessment of function-part 2.* Int J Sports Phys Ther, 2014. **9**(4): p. 549.
229. Cook, G., et al., *Functional movement screening: the use of fundamental movements as an assessment of function-part 1.* Int J Sports Phys Ther, 2014. **9**(3): p. 396.
230. Smith, J.J., P.J. Morgan, and R.C. Plotnikoff, *Smart-phone obesity prevention trial for adolescent boys in low-income communities: The ATLAS RCT.* Pediatrics, 2014. **134**(3): p. e723-e731.
231. Smith, J.J., P.J. Morgan, and R.C. Plotnikoff, *Rationale and study protocol for the 'Active Teen Leaders Avoiding Screen-time' (ATLAS) group randomized controlled trial: An obesity prevention intervention for adolescent boys from schools in low-income communities.* Contemp Clin Trials, 2014. **37**(1): p. 106-119.
232. Lubans, D.R., et al., *Assessing the sustained impact of a school-based obesity prevention program for adolescent boys: The ATLAS cluster randomized controlled trial.* Int J Behav Nutr Phys Act, 2016. **13**(1): p. 1-12.

233. Walters, B.K., C.R. Read, and A.R. Estes, *Effects of resistance training, overtraining, and early specialization on youth athletes: A literature review.* J Sports Med Phys Fitness, 2018. **58**(9): p. 1339-1348.
234. Lai, S.K., et al., *Do school-based interventions focusing on physical activity, fitness, or fundamental movement skill competency produce a sustained impact in these outcomes in children and adolescents? A systematic review of follow-up studies.* Sports Med, 2014. **44**(1): p. 67-79.
235. Moolyk, A.N., J.P. Carey, and L.Z. Chiu, *Characteristics of lower extremity work during the impact phase of jumping and weightlifting.* J Strength Cond Res, 2013. **27**(12): p. 3225-3232.
236. Stroube, B.W., et al., *Effects of task-specific augmented feedback on deficit modification during performance of the tuck-jump exercise.* J Sport Rehabil, 2013. **22**(1): p. 7-18.
237. Read, P.J., et al., *Reliability of the tuck jump injury risk screening assessment in elite male youth soccer players.* J Strength Cond Res, 2016. **30**(6): p. 1510-1516.
238. Comfort, P., et al., *Effect of knee and trunk angle on kinetic variables during the isometric midthigh pull: Test–retest reliability.* Int J Sports Physiol Perform, 2015. **10**(1): p. 58-63.
239. Bebich-Philip, M.D., et al., *Adaptation of the resistance training skills battery for use in children across the motor proficiency spectrum.* Pedatr Exerc Sci, 2016. **28**(3): p. 473-480.
240. Pichardo, A.W., et al., *Effects of combined resistance training and weightlifting on motor skill performance of adolescent male athletes.* J Strength Cond Res, 2019. **Published ahead of print**.
241. Pichardo, A.W., et al., *Integrating resistance training into high school curriculum.* Strength Cond J, 2019. **41**(1): p. 39-50.
242. Powell, C., J. Jensen, and S. Johnson, *Functional performance measures used for return-to-sport criteria in youth following lower-extremity injury.* J Sport Rehabil, 2018. **27**(6): p. 581-590.
243. Rumpf, M.C., et al., *Kinetic asymmetries during running in male youth.* Phys Ther Sport, 2014. **15**(1): p. 53-57.
244. Faigenbaum, A.D. and C. Polakowski, *Olympic-style weightlifting, kid style.* Strength Cond J, 1999. **21**(3): p. 73-76.
245. Kuklick, C.R. and B.T. Gearity, *A review of reflective practice and its application for the football strength and conditioning coach.* Strength Cond J, 2015. **37**(6): p. 43-51.
246. Handcock, P. and T. Cassidy, *Reflective practice for rugby union strength and conditioning coaches.* Strength Cond J, 2014. **36**(1): p. 41-45.
247. Tod, D.A., K.A. Bond, and D. Lavallee, *Professional development themes in strength and conditioning coaches.* J Strength Cond Res, 2012. **26**(3): p. 851-860.
248. Harries, S.K., D.R. Lubans, and R. Callister, *Comparison of resistance training progression models on maximal strength in sub-elite adolescent rugby union players.* J Sci Med Sport, 2016. **19**(2): p. 163-169.
249. Harris, N.K., et al., *Acute responses to resistance and high-intensity interval training in early adolescents.* J Strength Cond Res, 2017. **31**(5): p. 1177-1186.

Appendices

Appendix I. Conference abstract presentations

1. **Pichardo, A.W.**, Harrison, C.B., & Maulder, P.S. (2018). *Influence of maturation, strength and movement competency on motor skill performance in adolescent males.* Oral presentation. International Conference of Strength Training, Perth, Australia, November 2018.

2. **Pichardo, A.W.**, Harrison, C.B., Oliver, J.L., Maulder, P.S., Cronin, J.B., & Lloyd, R.S. (2017). *The relationship between maturation and athletic motor skills in youth males.* Oral presentation. Sport and Exercise Science New Zealand conference, Cambridge, New Zealand, October 2017.

3. Maulder, P.S. & **Pichardo, A.W** (2016). *The effect of functional movement training on sprint performance in youth males.* Poster presentation. Sport and Exercise Science New Zealand conference, Cambridge, New Zealand, October 2016.

Appendix II. Ethical approval for Chapters 4-6.

AUTEC Secretariat

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

29 March 2017

John Cronin
Faculty of Health and Environmental Sciences

Dear John

Re Ethics Application: **17/11 The benefits of resistance training with and without weightlifting for youth athlete development in males**

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

Your ethics application has been approved for three years until 29 March 2020.

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

- A brief annual progress report using form EA2, which is available online through http://www.aut.ac.nz/researchethics. When necessary this form may also be used to request an extension of the approval at least one month prior to its expiry on 29 March 2020;
- A brief report on the status of the project using form EA3, which is available online through http://www.aut.ac.nz/researchethics. This report is to be submitted either when the approval expires on 29 March 2020 or on completion of the project.

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

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

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

All the very best with your research,

K O'Connor

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

Cc: andrew.pichardo6@gmail.com

Appendix III. Information sheet for Chapters 4-6.

Participant Information Sheet

Date Information Sheet Produced:

24 March 2017

Project Title

The Benefits of Resistance Training with and without Weightlifting for Youth Athlete Development in Males

An Invitation

My name is Andrew Pichardo and I am a PhD student at AUT and Director of Athlete Development at St John's College. I would like to invite you to participate in this study that is being conducted as part of my PhD. Participation in this research is entirely voluntary and you are able to withdraw from the study at any time. Although I will know who is participating in the research, your involvement in this study will not impact your selection into future sports science classes, the athlete development programme, or any sports teams as I am not the teacher in charge of the programme and am just a student researcher.

To mitigate any imbalance of power, Wintec, an independent third-party, will assist with data collection and will remove any identifying information before turning over to me to analyse.

What is the purpose of this research?

This research is being conducted to understand how resistance training and weightlifting movements (snatch and clean & jerk variations) affect youth athletic development in males. Your movement skill, strength, power, and risk of injury will be measured over the course of the year to determine the effectiveness of the training programmes.

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

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

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

- Between 11 and 15 years of age (year 9 or 10)
- You are male
- You are healthy, injury-free and not taking medication
- You are enrolled in the Athlete Development Programme or physical education (PE) class

What will happen in this research?

The research involves examining how different training programmes influence movement skill, athletic motor skills, strength, power, and risk of injury markers. The experimental groups will be matched with classmates of similar maturity and jump ability and placed in a resistance training or resistance training + weightlifting group. Both groups will do some similar movements (such as back squat, overhead press, etc.) and some unique to the group (jump squat for resistance training group vs power clean for weightlifting group). The control group of PE students will not perform the trainings but will participate in the data collection sessions. Each term will include an approximately 8-week training block with a week or two of data collection. Data collection will occur at the beginning of term 1 and at the end of terms 1-4. The tests included will involve several movement screens, vertical and horizontal jumping, sprinting and change of direction tests, an isometric mid-thigh pull, and risk of injury tests examining balance and landing technique. During some of the data collection sessions, various bodyweight movements will be filmed with digital cameras from the front and side and retrospectively rated according to different criteria previously established to assess movement competency. These movements include bodyweight movements such as squats, lunges, and push ups. I will then analyse the data to determine effectiveness of the different training programs compared to a typical amount of improvement due to maturity from the control group.

The control group made of PE classes will not follow the intervention training protocol but will still be involved in all data collection sessions.

What are the discomforts and risks?

It is not expected that you will experience discomfort or risk beyond that of participating in your normal sports training. You might feel fatigue or soreness from doing a new type of training. Injury in youth due to resistance training is most commonly from unsupervised training and includes pinching or dropping of weights. However, the training groups will always be supervised by a qualified coach and there is little risk or discomfort associated with the data collection procedures.

How will these discomforts and risks be alleviated?

Ensuring you are paying attention to instructions and aware of your surroundings will help alleviate the risks and discomforts. Proper cool-down after training sessions can also help reduce discomfort of training sessions and will be performed at the end of each session.

What are the benefits?

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

- Discovering your ability to perform basic movements
- Knowing how fast you can run over 10, 20, and 30 m, how well you change direction, and how well conditioned you are
- Learning how high and far you can jump on one or both legs
- Learning how strong your lower body is
- Learning about your risk of injury and ways to improve this
- Feedback on how you compare to the group averages

All subjects will receive the benefits of the data collection. Of the training groups, benefits may vary depending on the type of training performed. The findings of the proposed research will be valuable for sport coaches and athletes as well as strength and conditioning coaches and sports scientists.

Finally, this research will benefit myself, as this study will be included in my PhD thesis.

What compensation is available for injury or negligence?

In the unlikely event of a physical injury as a result of your participation in this study, rehabilitation and compensation for injury by accident may be available from the Accident Compensation Corporation, providing the incident details satisfy the requirements of the law and the Corporation's regulations.

How will my privacy be protected?

All of the data from this study will be primarily collected from Wintec and de-identified before turning over to me. That means that your name or contact information will not be available outside of the research database. The data from this research will be made available for approved researchers without any additional consent beyond that given by yourself or guardian. I will keep all of your data confidential and any data published or used for presentations will be anonymous.

What are the costs of participating in this research?

All training and testing sessions will be performed during school curriculum time. However, some testing may run over into break times, so this may require some extra time involvement (30 minutes max). The training and testing weeks will take place during 9 of the weeks each term with each session lasting twice a week for one hour each.

What opportunity do I have to consider this invitation?

You have 1 week to decide whether or not you would like to participate in this study.

How do I agree to participate in this research?

If you are under 16 years of age and would like to participate in this study your guardian will need to fill out and sign a Guardian Consent Form (see attached) and you will need to fill out and sign an Assent Form (see attached).

Will I receive feedback on the results of this research?

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

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

Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor, *Professor John Cronin*

Email: john.cronin@aut.ac.nz

Phone: + 64 9 921 921 x 7523.

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

Whom do I contact for further information about this research?

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

Researcher Contact Details:

Andrew Pichardo

Email: apichardo@stjohns-hamilton.school.nz

Project Supervisor Contact Details:

Professor John Cronin

Email: john.cronin@aut.ac.nz

Phone: *+ 64 9 921 921 x 7523*.

Approved by the Auckland University of Technology Ethics Committee on *29/03/17*, AUTEC Reference number *17/11*.

Appendix IV. Parental/Guardian Consent Form

Parent/Guardian Consent Form

TE WĀNANGA ARONUI O TĀMAKI MAKAU RAU

Project title: **The Benefits of Resistance Training with or without Weightlifting for Youth Athlete Development in Males**

Project Supervisor: ***Professor John Cronin***

Researcher: ***Andrew Pichardo***

O I have read and understood the information provided about this research project in the Information Sheet dated 24 March 2017.

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

O I understand that I may withdraw my child/children or any information that I have provided for this project at any time prior to completion of data collection, without being disadvantaged in any way.

O My child is am not suffering from heart disease, high blood pressure, any respiratory condition (mild asthma excluded), any illness or injury that impairs their physical performance.

O I agree to my child/children taking part in this research.

O I wish to receive a copy of the report from the research (please tick one): YesO NoO

Child/children's name/s :…………………………………………………………………………………

……

Parent/Guardian's signature:……………………………………………………………………………………

Parent/Guardian's name:…………………………………………………………………………………………

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

……………………………………………………………………………

……………………………………………………………………………

……………………………………………………………………………

……………………………………………………………………………

Date:

Approved by the Auckland University of Technology Ethics Committee on 29/03/17 AUTEC Reference number 17/11

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

2 July 2015 page 1 of 2 This version was last edited in July 2015

Appendix V. Participant Assent Form

Assent Form

Project title: **The Benefits of Resistance Training with or without Weightlifting for Youth Athlete Development in Males**

Project Supervisor: ***Professor John Cronin***

Researcher: ***Andrew Pichardo***

O I have read and understood the information provided about this research project in the Information Sheet dated 24 March 2017.

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

O I understand that I may withdraw myself, or any information that I have provided for this project at any time prior to completion of data collection, without being disadvantaged in any way.

O I am not suffering from heart disease, high blood pressure, any respiratory condition (mild asthma excluded), any illness or injury that impairs my physical performance.

O I agree to run, jump, throw, and perform basic movements for multiple trials and have the distances and times recorded.

O I agree to perform the exercises required for the intervention to the best of my ability.

O I agree to allow indefinite storage of my de-identified data.

O I agree to take part in this research.

O I wish to receive a copy of the report from the research (please tick one): YesO NoO

Participant's signature:...

Participant's name:...

Participant Contact Details (if appropriate):

………………………………………………………………………………………

………………………………………………………………………………………

………………………………………………………………………………………

………………………………………………………………………………………

Date:

Approved by the Auckland University of Technology Ethics Committee on 29/03/17 AUTEC Reference number 17/11

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

Appendix XI. Confidentiality Agreement

Confidentiality Agreement

Project title:	*The Benefits of Resistance Training with or without Weightlifting for Youth Athlete Development in Males*
Project Supervisor:	***Professor John Cronin***
Researcher:	***Andrew Pichardo***

O I understand that all the material I will be asked to record is confidential.

O I understand that the contents of the Consent Forms, video recordings and other data can only be discussed with the researchers.

O I will not keep any copies of the information nor allow other third parties access to them.

Intermediary's signature: ....

Intermediary's name: ....

Intermediary's Contact Details (if appropriate):

....

....

....

....

Date:

Project Supervisor's Contact Details (if appropriate):

....

....

....

Approved by the Auckland University of Technology Ethics Committee 29/03/2017 AUTEC Reference number 17/11

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