Power development and trainability in youth

A thesis submitted to Auckland University of Technology in fulfilment of the requirements

for the degree of

Doctor of Philosophy

September 2013

Sports Performance Research Institute New Zealand (SPRINZ)

School of Sport and Recreation

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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 institution of higher learning.

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September, 2013.

Candidate contribution to co-authored works

The contribution of co-authors for publications (e.g. Meylan, C., 80%) arising from these studies and from whom approval has been granted for inclusion in this doctoral thesis, is as follows:

Published in peer-reviewed journals

Meylan, C. (80%), Cronin, J. (10%), Oliver, J. (5%), Hughes, M. (5%) (2010) Talent identification in soccer: the role of maturation status on physical, physiological and technical characteristics. *Int J Sports Sci Coach.*, 5(4), 571-592. (Chapter 2).

Meylan, C. (80%), Cronin, J. (5%), Oliver, J. (5%), Hughes, M. (2.5%), McMaster, T. (2.5%) (2012) The reliability of jump kinematics and kinetics in children of different maturity status. *J Strength Cond Res.*, 26(4), 1015-1026. (Chapter 4).

In press in peer-reviewed journals

Meylan, C. (80%), Cronin, J. (5%), Manson, S. (5%), Oliver, J. (2.5%), Hughes, M. (2.5%), (2013) An integrative model of power development in youth football. *Int J Sports Sci Coach.*, In Press (accepted in June 2013) (Chapter 3).

Meylan, C. (80%), Hopkins, W. (10%), Cronin, J. (5%), Oliver, J. (5%) (2013) Adjustment of measures of strength and power in youth male athletes differing in body mass and maturation. *Pediat Exerc Sci.*, ahead of print (accepted in July 2013) (Chapter 7).

Meylan, C. (80%), Cronin, J. (5%), Hopkins, W. (5%), Oliver, J. (2.5%), Contreras, B. (2.5%) (2013) The effect of maturation on adaptations to strength training and detraining in 11- to 15- years old. *Scand J Med Sci Sports*, ahead of print (accepted in August 2013) (Chapter 9).

Under review in peer-reviewed journals

Meylan, C. (80%), Cronin, J. (7%), Pinder, S. (5%), Oliver, J. (2%), Hughes, M. (2%), Jidovstseff, B. (2%) (2013) Isoinertial assessment of the force-velocity-power profile and maximal strength in youth. *Sports Biomech.*, in second review (Chapter 5).

Meylan, C. (80%), Cronin, J. (10%), Oliver, J. (5%), Rumpf, M. (5%) (2013) Sex-related differences in explosive actions during late childhood. *J Strength Cond Res.*, in second review (Chapter 6).

Meylan, C. (80%), Hopkins, W. (10%), Cronin, J. (5%), Oliver, J. (2.5%), Pinder, S (2.5%) (2013) The contribution of vertical strength and power to sprint performance in youth. *Int J Sport Med.*, in second review (Chapter 8).

Conference presentations

Meylan, C. (80%), Cronin, J. (5%), Hopkins, W. (5%), Oliver, J. (2.5%), Contreras, B. (2.5%) (2013) The effect of maturation on force, velocity, power and speed adaptations to strength training and detraining in youth. *NSCA 36ᵗʰ Annual National Conference*, Las Vegas, USA.

Meylan, C. (85%), McMaster T. (10%), Cronin, J. (5%) (2012) Ballistic profiling in youth. *International Convention on Science, Education and Medicine in Sport 2012*, Glasgow, Scotland.

Rumpf, M. (50%), Meylan, C. (40%), Cronin, J. (10%) (2010) Reliability of a change of direction test for team sport. *SPRINZ Conference 2010*, Auckland, New Zealand.

Book chapter

Meylan, C. (50%), Cronin, J. (50%) (2013). Talent identification. In: *Strength and Conditioning for Young Athlete: Science and Applications*, Oliver, J., Lloyd, R (eds), Oxford: Routledge Publishers

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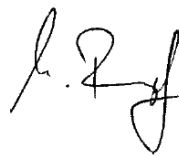
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Acknowledgements

"It is the people who make a place great" (JC quote) and you certainly made New Zealand awesome.

Finally, I would like to dedicate my thesis to my beautiful partner Melanie and my Family. Your love and care allowed me to keep going full pace for the last four years. I had a vision and you trusted me. I was always able to lean on your shoulder when times got tough. Without you, none of this would have been possible.

Ethical approval

Ethical approval for this thesis research was granted by the Auckland University of Technology Ethics Committee (AUTEC). The AUTEC references were:

- 10/75 **The reliability of kinematic and kinetic jump variables in children of different maturity status.** Approved on 6th July 2010
- 10/74 **The reliability and validity of maximum strength and force-velocity-power profiling in males of different maturity status.** Approved on 2nd July 2010.
- 10/55 **Coordination-agility vs. strength-power training in prepubescent athletes.** Approved on 3rd June 2010.
- 11/122 **The effect of high-load low-velocity strength training on power and sprint performance in children of different maturity status.** Approved on 7th June 2011.

Abstract

Power is regarded as a major attribute for most team sport players, therefore it's advancement should be taken into consideration early in an athlete's developmental pathway. However, the natural development of power and its trainability during growth and maturation remains relatively unaddressed by researchers. Subsequently, the purpose of this thesis was to investigate the variability of isoinertial force-velocity profiling and maximal strength assessment in youth and determine the role of maturation and training on the variables deemed reliable. A great deal of movement variability in the eccentric phase of counter movement jumps was found, especially prior to peak height velocity (PHV). Vertical concentric mean and peak power and eccentric mean power were deemed reliable to monitor stretch-shortening cycle performance, while the assessment of force-velocity-power and maximal strength can be measured reliably with a ballistic loading protocol after familiarization. Vertical and horizontal power can be normalised to body mass with a common sex allometric scaling factor in athletes between 9-12 years old and sex difference in relative acyclic power did not appear prior to male puberty in contrast to sprint and change of direction performance. Tracking somatotype, age, maturity and body mass during growth was found important to better understand the development of explosive actions. In male pre to post PHV, strength and power measures were found to have a greater dependency on body mass than velocity-related variables, and even after adjustment for body mass most differences remained substantial. Maturity dependant improvements, along with appropriate adjustment for body mass, need to be taken into account when comparing performance of maturing athletes. Percent differences in strength or power had percent effects on sprint performance that were similar at different stages of maturity. These relationships explained most of the maturity related improvements in sprint performance before PHV but only some improvements after, meaning that other neuromuscular factors are playing a role in sprint performance development. Specific strength training is recommended for athletes around PHV rather than prior to PHV to improve strength, power and speed, while maintenance programs in youth should be planned to reduce decay in these variables, especially in pre and post PHV boys. While the development of power is dependent on a multitude of factors, maturity had an influence on the timing and tempo of power development as well as the training dose-response relationship and rate of decay.

18

Chapter 1: Introduction

Background

Power is regarded as a major attribute for most elite team sport athletes (e.g. soccer, rugby, basketball, ice hockey, etc.) and its development should be taken into consideration early in an athlete's pathway [1, 2]. The talent identification process to uncover and develop gifted athletes is undertaken by many clubs and federations and has been reviewed [3]. Advanced maturation results in greater power output [4], which helps to win one on one challenges and can influence the coaches' view of a player. From the perspective of identifying gifted players, it is therefore crucial to determine the maturity status of players to truly interpret their physiological performance in a laboratory (e.g. power output on force plate) and field (e.g. ability to win challenges) setting. Such an approach also allows the power output differences between players of various maturity status and different determinants of muscle power during growth and maturation to be identified.

Based on performance spurts of the different athletic characteristics, the concept of windows of trainability was introduced in the long-term athlete development model to articulate optimum timing to train a certain athletic characteristic during growth and maturation [5, 6]. The current long-term athlete development model provides no indication of a window of trainability for power development during childhood [1]. This may be because components of power (i.e. force and velocity) have their own separate windows of trainability included in the long-term athlete development model. However, given the importance of muscular power in sport and its dual composite (i.e. force and velocity), it may be appropriate to consider the growth periods during which the training emphasis for maximal power should occur. Owing to the minimal number of longitudinal studies examining the interaction of growth, maturation and trainability on muscular power [7], it is difficult to identify a potential window of trainability to maximize power development. Therefore a thorough review on the implementation of training methods for power development specific to a sport would seem the most informative procedure to create a long-term plan for sport specific power development.

In the context of talent identification and development (TID), monitoring maximal power output is thought important [1]. The variable can be measured during brief maximal

intensity exercise such as cycling, sprinting or jumping. The assessment of "true" peak power requires measurements of instantaneous values of force and velocity [8, 9]. These instantaneous variables are typically measured using a force platform [10], non-motorized treadmill with in-built force plates [11], or cycling protocols [12-14]. Cycling force-velocity power profiles of children and adolescents have been found to be reliable [15, 16] but the validity of such tests for field sport athletes is questionable [9]. Force-velocity-power profiling using loaded jump squats is widely used in recreational and elite athletes [17, 18] and has been investigated in athletic children and adolescents [19-21]. However, this method may not be appropriate in pediatric populations due to poor squatting technique and overloading of the growing spine. Previous studies have demonstrated the safety of a supine squat machine with novice weight trainers during ballistic movement [22, 23]. As this movement simulates jump mechanics, it could be used to determine the force-velocity power profiles of athletes of different age groups. Inertial dynamometers (e.g. linear position transducers or accelerometers) can be used in combination with this equipment [22] and have been used with adults to create load/force-velocity profiles and estimations of one repetition maximal (1RM) according to the force-velocity relationship [24]. Therefore, this assessment is of great interest, as it can be safely administered and can be used concurrently for isoinertial 1RM prediction and force-velocity-power profiling of children of different maturity status, which has not been quantified previously.

The force-velocity power profile is affected by morphological and neural factors that are changing during growth and maturation. Force is directly proportional to the muscle cross-sectional area (MCSA) [25, 26], which increases during growth and therefore contributes to increased power output. The maximal shortening velocity is dependent on the length of the myofibrils and the fibre type composition [27, 28]. Both factors are believed to change with growth and increases in shortening velocity might be expected to influence the velocity-dependent force and power relationship [8]. Considerable changes associated with growth and maturation are therefore likely to influence force, velocity and subsequently power output and could explain differences in these parameters between children of different maturity status. For instance, when muscle force is normalised to the muscle cross-sectional area or muscle volume, the differences in muscle force between age and gender are reduced [26, 29]. Therefore, data analysis needs to account or scale for these biological differences to determine the role of quantitative (i.e. body size) and qualitative (i.e. body tissue and structure) characteristics in performance [30]. The objective of scaling

20

is to produce a "size free" variable. Traditionally, the ratio standard is used in scaling (e.g. power/body mass), which assumes a linear relationship between performance and body size dependent variables and an intercept of 0 [31]. However, this linearity only appears in "exceptional circumstance" and if it is not satisfied, a distortion is introduced [32]. Consequently, for many physiological performance parameters (e.g. VO_{2max}, peak power), ratio scaling fails to produce a body dimensionless index [33-35]. Appropriate statistical analysis includes analysis of covariance (ANCOVA) and allometric modelling [30, 31]. The assumed linear relationship for ANCOVA is not always present and the error about regression is not necessarily additive but might be multiplicative [33, 36]. When this is the case, allometric modelling must be used [30, 33, 36]. This form of scaling has been found to be more appropriate than ratio scaling to distinguish physiological abilities of different populations [37, 38]. However, no studies have use allometric scaling to account appropriately for body mass when investigating force-velocity-power profiling in ballistic movement (e.g. jumping) and training adaptations in pediatric populations.

It is well accepted that muscle strength at a given velocity will increase during growth [25, 35] and consequently power will also be greater. Specific training during growth complements this process and increases performance. Strength training has been found to be effective at improving strength in children and adolescence [39-42]. However, only a few studies have investigated the relative [43-46] and absolute [45-47] strength adaptations of a given training regime across different maturity groups. In addition, information as to the effect of strength training on instantaneous power output and the force-velocity relationship remains scarce [48]. Several studies have investigated the transfer of strength gains on indirect measure of power (i.e. jump height, standing broad jump and sprinting) but the results are equivocal [41, 49-51]. Given the differences of the neuromuscular systems capability during growth [52], a training stimuli may induce various adaptations depending on maturity status, which would support the theory of "windows of trainability" and could lead to the implementation of specific training emphasis periods [1]. Additional studies that include distinct maturity groups, accurate assessment of instantaneous power, and comparable training programs across levels of maturity are required to give insight into the windows of trainability of leg power.

Originality and research aims

The purpose of this doctorate thesis is to establish the role of human development and a training intervention on the isoinertial force-velocity-power profile and maximal strength of youth. With context to the purpose statement, seven key areas of investigation account for the originality of this thesis and drive the research aims:

- The methodological issues associated with physical testing in talent identification and development still need to be reviewed to provide guidance and clarity in both practical and research settings.
- Long-term athlete development models have not taken into account comprehensive training emphasis periods for power and its application into a sport specific model.
- The variability associated with isoinertial assessment of the force-velocity-power profile and maximal strength in youth is yet to be determined.
- The sex-related differences in explosive actions during late childhood as well as the gender-specific factors responsible in these actions still need to be investigated.
- There is limited knowledge as to the quantitative and qualitative neuromuscular factors accounting for the change in strength and force-velocity profiles during growth and maturation.
- The contribution of vertical strength and power to sprint performance in youth has not been investigated.
- Whether maturity has an effect on strength, power, speed and mechanical adaptations after a strength training program and influence the decay of these performance measures is yet to be determined.

Significance of study

Power is linked to successful team sport performance, so that it is regularly tested both from a talent identification and development perspective. However, the role of growth and maturation in power development is still unclear and often acts as a misleading and confounding factor in TID. Clarity and guidance in power assessment and development is needed to create an efficient TID program in a sport-specific setting.

To accurately assess power, laboratory methods need to be developed. To date only indirect field measurement (e.g. sprinting, jump length and height) and cycling tests have been used to quantify the force-velocity-power profile in pediatric populations. The use of a safe instrumented weight machine allows force-velocity-power profiling of athletes during ballistic movements, but has not been used in youth populations. Such analyses should provide a better understanding of power output during growth, the contribution of its component parts (i.e. force and velocity) and the influence of physical factors such as body mass.

Finally, considering the changes occurring during human growth, previous authors have argued that there are optimal periods to train certain components of performance (i.e. training emphasis periods). However, maturity effects on force-velocity-power profiling and maximal strength adaptation using strength training are still unexplored. Such research should provide better guidance on the application of a specific training mode to enhance strength and power throughout a player's pathway.

Thesis organisation

The main aims of the thesis are to: improve our understanding of maximal strength and force-velocity-power profiling in youth populations; and, quantify the influence of growth and maturation and specific training interventions on these neuromuscular characteristics. The thesis is structured into four stages addressing key areas related to the main objective (see Figure 1.1). The design of this thesis consists of two literature reviews (Chapters 2 and 3) and six original experimental investigations (Chapters 4–9), all of which have been submitted as a stand-alone paper to international peer-reviewed journals. Subsequently, each chapter is presented in the format of the journals for which they were written, with the exception that each study is preceded by a brief explanatory prelude rather than an abstract.

For consistency, all referencing is in *Sports Medicine* Journal format (modified *Vancouver* style), and for ease of reference, a single citation summary is contained at the end of the thesis.

Stage one "Modeling power in talent identification and development of youth soccer players" (Chapters 2 and 3) reviews the role of growth and maturation and training intervention on power development from a TID perspective in a soccer-specific context. Player pathways and physical requirements tend to be sport-specific and using this context provides a more detailed practical approach/model that can be adapted to other sports. Since soccer presented the largest body of literature in youth, has by far the largest worldwide participation rates in children and can be related to many team sports, it was preferred to other sports. Subsequent chapters in this thesis focused on the limitations and recommendations highlighted in the literature reviewed.
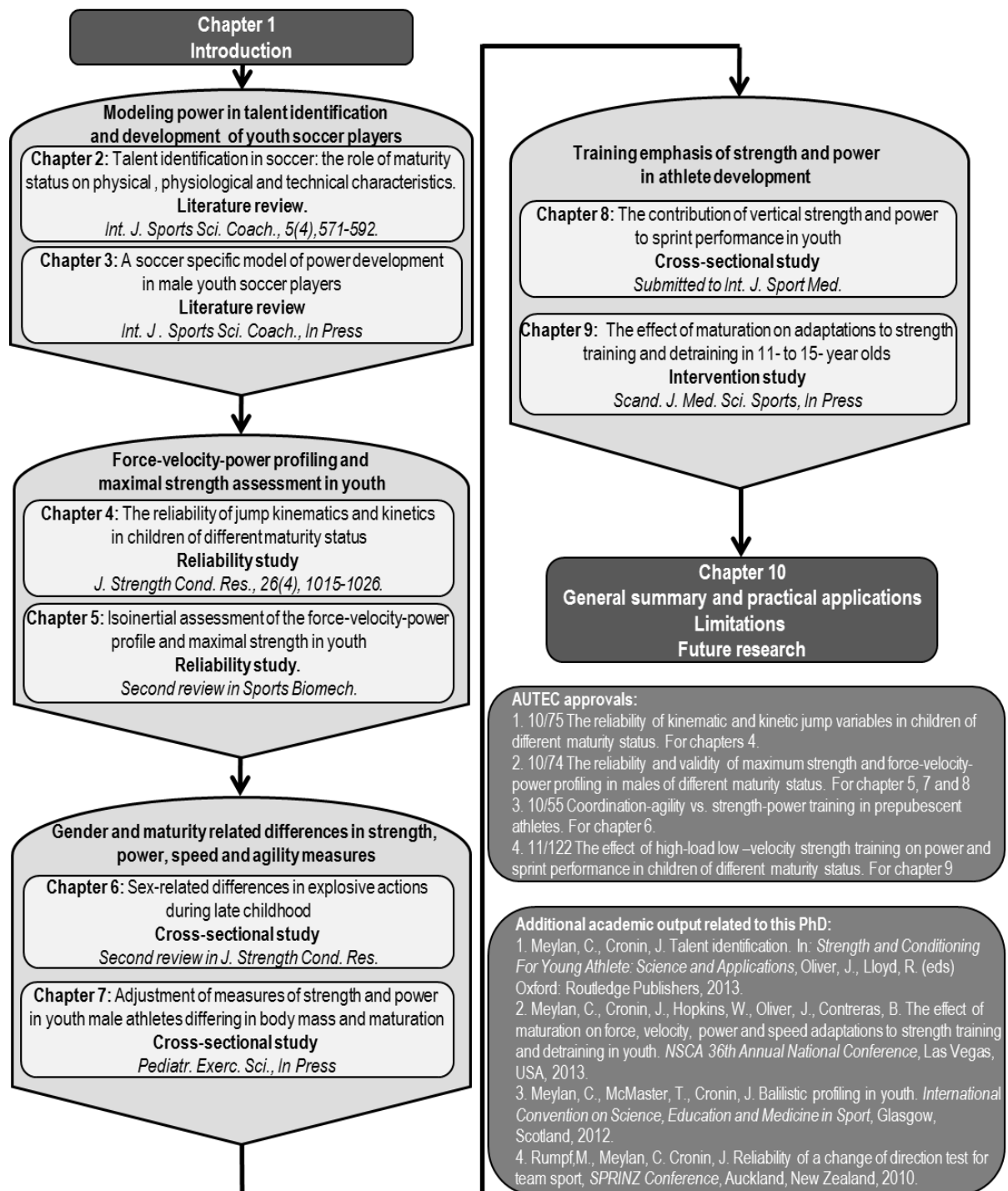
Figure 1.1. Overview of the thesis structure.

Stage 2 (Chapters 4 and 5) determined the variability associated with maximal strength assessment and force-velocity-power profiling in youth, and whether maturity status was likely to influence the reliability of these measures. This analysis enabled the identification of variables that would be used in the subsequent chapters of this thesis and could be used by practitioners to monitor the performance of youth athletes.

Stage 3 (Chapters 6 and 7) investigated the differences in strength, power, speed and agility measures between athletes of different gender and maturity status. Allometric scaling was used to account for body mass and produce "size free" variables for comparative analysis. A best predictor model of power, speed and agility was generated for both genders to further understand the role of maturity and anthropometric characteristics in athletic performance in youth.

Stage 4 (Chapters 8 and 9) investigated the role of maturation in strength, power, and speed development as well as mechanistic adaptations to training. The contribution of strength and power to sprint performance was investigated to determine the importance of these neuromuscular characteristics in a key athletic performance and suggest training emphasis periods in a player's pathway. Strength training was implemented across different maturity groups in order to determine the influence of maturity status on training adaptations and guide best practice in athletic development.

The final chapter of this thesis (Chapter 10) consists of a general summary of findings with limitations and future research directions as well as a conclusion and practical recommendation section for practitioners. Finally, an overall thesis reference list and appendices that present relevant peripheral material including informed consent forms, ethics approval, subject information sheets and abstracts (as submitted for publication), has been collated to assist with review or future recreation of research arising from this thesis.

Chapter 2: Talent identification in soccer: the role of maturity status on physical, physiological and technical characteristics

Prelude

Researchers investigating soccer talent identification and development (TID), as with other sports, have reported a systematic bias in selection towards players born early in the year (i.e. relative age effect) and early maturers. There is interest in investigating the physiological (e.g. power) and technical (e.g. dribbling) characteristics of players of different maturity status to determine if there is a tendency for early maturers to perform better in these tests, potentially exposing some of the underlying factors that bias youth players selection. The physical, physiological and technical characteristics of these players may not be determinants of professional status at a later stage and recognising the tests and characteristics associated with future success at youth level may provide valuable information for TID programs. Estimating maturity status and scaling performance for body size may allow comparison of players more accurately and guide coaches to make better decisions during the selection process of youth players. Based on these premises, the purpose of this paper is to provide a review around TID in soccer that use physiological and technical testing procedures, and to summarise the issues associated with this process.

Introduction

Soccer is characterised by repetitive intermittent bursts of activities during which forceful and explosive actions, such as sprinting, jumping tackling, kicking, turning and changing pace are occurring. These high intensity activities have a critical influence on match performance [53] and need to be developed from a young age. Towards these ends, many national federations and professional clubs invest considerable resources to identify young gifted players. Considering the importance of repetitive explosive actions and winning challenges in soccer, the talent identification process usually involves a physical (i.e. anthropometry) and physiological (i.e. performance measures: speed, strength, aerobic and anaerobic power) testing battery relevant to the demands of the sport. However, a one-dimensional approach in talent identification based on physical and physiological parameters can be misleading. Rather, a multidisciplinary approach addressing physical, physiological, technical, sociological and psychological predictors should be conducted [3, 54, 55]. An important issue is that excellence in a sport is not dependant on one standard set of skills but can be achieved in unique ways through different combination of abilities. This effect has been termed the "compensation phenomenon" and it has been suggested that deficiencies in one area of performance may be compensated for by strength in others [56]. Furthermore physically dominant players at junior level may not maintain this advantage into adulthood [57]. It has been suggested that variables such as cognitive-perceptive skills (anticipation or decision-making) may also be of importance in talent identification and development in soccer [54, 58, 59].

Nevertheless, profiling of young players according to physical and physiological testing may still provide valuable data for the talent identification and development process to determine a certain potential to become a professional player [60]. Previous literature [3, 61] has offered a differentiation between "giftedness" and "talent". Giftedness designates the possession and use of high levels of natural aptitudes in a domain and can be recognised by the rate of learning, rather than level of performance. Talent is the superior mastery of systematically developed skills. The development process is described as the transformation of gifts into talent (i.e. the outstanding skills developed in a particular sport, through a process of maturation, learning, training and practice) [3, 61]. In this sense, monitoring physical and physiological changes due to maturation and training allow the progress of the player and responsiveness to various training stimuli to be determined.

Often growth and maturation are used interchangeably but they have specific definitions. Growth refers to observable step-by-step changes in quantity and measurable changes in body size such as height, weight and fat percentage. Maturation refers to qualitative system changes, both structural and functional, in the body's progress toward maturity such as the change of cartilage to bone in the skeleton, appearance of pubic hair or menstruation [52]. Maturation is a process whereas maturity is a state. The timing and tempo of maturation varies greatly between individuals during growth. Timing refers to when specific maturational events occur (e.g. age at PHV) and tempo refers to the rate at which maturation progresses. Also, all tissues, organs and systems of the body mature with growth, but they do so at different times and rates [52]. As a result, assessment of biological maturity status varies with the bodily system considered (e.g. skeletal maturity, sexual maturity) [62]. Performance spurts (e.g. speed, power, endurance) may occur at different chronological ages depending on the maturation tempo and timing. These differences in an individual's timing and tempo is referred to as the *time-spreading effect* [63]. Advanced age and/or maturity can create advantages in strength, power and speed and led to systematic selection of older (i.e. relative age effect) [64] and more mature players [65-68] in the talent identification process. Therefore, the pitfalls in talent identification need to be addressed to raise the awareness of coaches and sport scientists as to the limitations of the talent identification process. In addition, the physical and physiological characteristics of young players need to be monitored in relation to the transient nature of maturity associated with variation. Also, considering that both game intelligence and technical skills could be linked to maturity status, it is of interest to associate them with these physical and physiological factors. To validate the use of physical, physiological and technical tests, the sensitivity of these tests for determining future success (i.e. professional status) needs to be investigated and practical solutions for performance analysis provided. Following the above rationale, the current article discusses the following three major themes: (i) misconceptions in talent evaluation; (ii) physical, physiological and technical characteristics of young soccer players of different levels and discriminative ability for future success and tactical positioning; and, (iii) recommendations for physical, physiological and technical testing and data interpretation in youth soccer. Due to the larger body of literature on youth male compared to youth female soccer players, the greater depth of the talent pool and scouting in the men's game, the difference in timing and tempo of maturation between the two genders, and their differences in physical and physiological

29

characteristics from the onset of puberty, this review will only focus on the literature related to male soccer players.

Misconception in talent evaluation

Entrance into a professional soccer academy and selection to national or state representative junior squads are often regarded as important stages in the development of future professional players. The players selected in these programmes are exposed to highly qualified coaches and national and international competitions. This selection process often occurs as early as 11 years old [69]. The "coach driven" method of talent identification rests on a multifaceted intuitive knowledge comprised of socially constructed "images" of the perfect player. When a coach selects a player, he/she usually has the feeling of doing something self-evident, logical, and inevitable as he/she distinguishes between different talented soccer players without being explicit about the generative principles that guide his observation. Choices of gifted players are therefore made on personal taste, knowledge and expertise and this process is viewed as legitimate by coaches. However, such an approach is highly subjective and can lead to repetitive misconceptions in talent evaluation [70].

During childhood and adolescence, differences in maturity can be extensive, even amongst individuals of the same chronological age. Whilst differences in age of less than 12 months have little relevance on adult physiques, they can have major significance in adolescents undergoing rapid rates of growth and development. Players who are born early in the selection year often have the advantage of being bigger, stronger, faster and having greater longevity in their sport [67, 71-73]. As a result, they may be more successful than their younger counterparts, resulting in greater motivation and commitment. Younger and less mature players may be regarded as less talented during the selection process [73, 74] or drop out because of low perceived competence and lack of success [68, 71, 74, 75]. This phenomenon creates a bias in the birth date distribution of selected players and is referred as the relative age effect (RAE) [76]. That is, the children born in the first 3-4 months from cut-off dates are over represented in team selection for various sports (see Musch and Grondin [71] and Colbey et al. [64] for extensive reviews on the topic). The selection process in soccer seems to create one of the largest RAE amongst sports [64]. The RAE is present across youth teams, from club [67, 74, 77-80] to national level [74, 77-79, 81, 82], with a progressive increased incidence with level of excellence [80]. The

RAE also remained persistent when a cut-off date for age category changed from the academic year (i.e. September to August) to the calendar year (i.e. January to December) [78, 81, 83]. This latter situation can reveal a problem around the selection process and the coaches' view of gifted players. In addition, even if reduced [80], this bias tended to persist at a senior level [74, 77, 80, 83, 84], supporting the hypothesis that children born early in the year have greater chance to succeed due to their more advanced maturity status during their junior years [83]. Unsurprisingly, the RAE is not apparent in sports where physical attributes can be seen as inefficient and other parameters, such as motor skills, are more important (e.g. dancing) [85, 86]. In this sense, the RAE may not only be created by the artificial selection process but also by "self-elimination" or "self-restriction" from the perceived enjoyment and success at a young age as well as schools orientating pupils in sports fitting their current abilities [72, 86, 87]. Recent studies [72, 87] have showed a RAE in the total licensed players in the French Soccer and Basketball federations in relation to the total population. Therefore, the RAE found in the previous studies [67, 74, 77-82] could have a methodological bias created by an initial RAE within the licensed players. Figure 2.1 illustrates the RAE at different youth levels based on the literature since 2000 [67, 78-80, 82, 88-90].
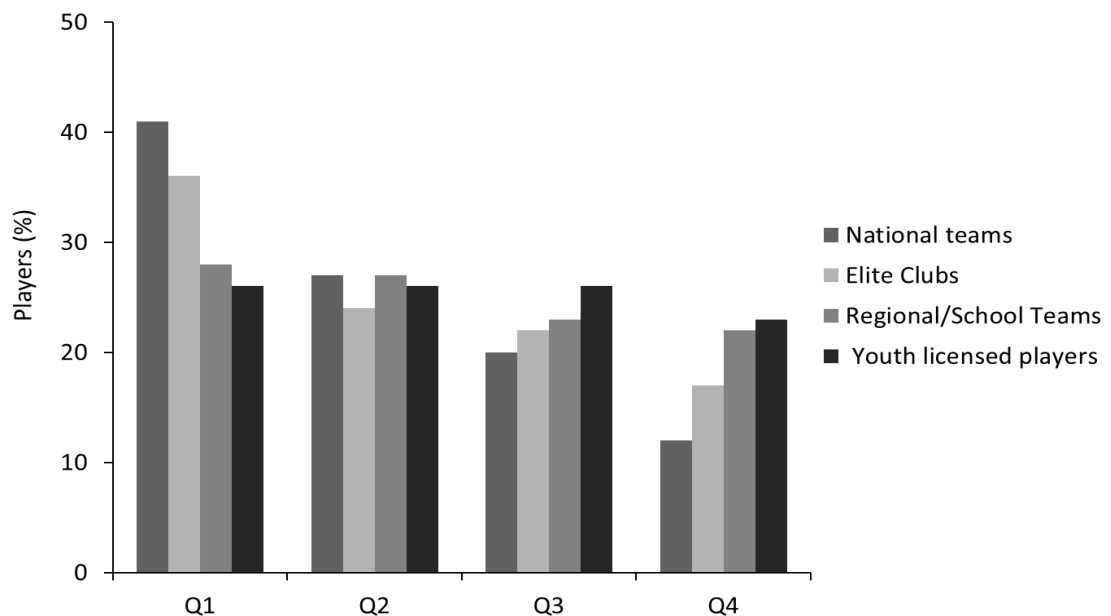
Figure 2.1. Summary of the relative age effect in youth soccer across different levels of play presented in the literature since 2000.
National teams players (U15-U21; N = 1450) [79, 88, 89], elite club level players (N = 5506) [67, 78-80, 82, 88, 89], Regional and school level players (N = 13216) [80] and French youth licensed players (N = 1,116,464) [90] birth date distribution are presented by Quartiles (Q1-Q4).

Considering the above comment, birth date distribution cannot be used alone to indicate a tendency to discriminate younger players or less mature players in talent identification. Also, early maturers of the third or fourth quartile can be as physically mature or more than late maturers of the first two quartiles [82]. In this context, an indication of maturity status would appear more relevant to this issue. Previous studies focusing on maturity status reported that elite youth soccer players were physically more mature than the normal population [73, 77, 91, 92]. Again, this might be due initially to the more mature state of soccer players compared to the total population. This said, early maturers were more represented in the selected teams than normal or late maturers [65-68] and late maturers were less represented at club level as age group increased [67, 93]. This trend is mostly observed between 13 to 16 years of age when the differences in maturity status are amplified by the timing and tempo of adolescent growth spurts [65, 67, 68, 93]. Therefore maturity may play a crucial role in the coaches' view on youth players' potential and the chance of a young player to sign a professional contract. The physical advantages afforded by age and advanced maturity status during adolescence are largely transient and are reduced or reversed in young adulthood [57]. Late maturers may be dismissed on the basis of their physical characteristics and not on their adult potential. On the other hand, youth "talented" players may fail to meet adult expectations as their late-maturing peers who persist in the sport catch-up in size, speed, strength and power. This hypothesis is confirmed by the reduced RAE in senior professional players compared to elite youth players [80]. If physical and physiological characteristics may be appealing for initial talent identification, their ability to successfully predict a subsequent professional career is debateable [60, 82, 94]. Those involved in the identification and developments of gifted soccer players need to be aware of the contributions of growth and maturation as such to the functional and skill demands of soccer and multiple objective criteria are necessary when screening for gifted players.

Physical, physiological and technical testing in youth soccer

Considering the differences in birth date distribution and maturity status differences between elite and non-elite level in youth soccer players, the purpose of this section is to investigate three major concerns related to physical, physiological and technical testing, currently used in youth soccer in talent identification and estimation of superior soccer

performance: 1) the influence of maturation timing and tempo on physical, physiological and technical characteristics of youth soccer players; 2) the sensitivity of physical, physiological and technical characteristics to determine current (i.e. elite vs non-elite) and future success (professional vs. non-professional) of youth soccer players; and, 3) the role of physical, physiological and technical profiles of youth players in the coaches' tactical decision making about playing position. The articles included in this section reported: a measure of maturity status (e.g. skeletal age); physical characteristics (e.g. height, mass); physiological performance (e.g. speed) and/or technical abilities (e.g. dribbling) of male youth soccer players. The studies that satisfied the inclusion criteria are presented in Tables 2.1 and 2.2.

Table 2.1. Physical and physiological factors used in youth soccer to discriminate between early, on average and late maturers; elite, sub- elite and non-elite players; and, future international, professional and amateur players.

Authors	Players	Groups	Mat.	Anthropo.	Physical testing	Significant gradient (> = better; p > 0.05)
Carling et al. [82]	N = 160 U14 National level	Future national team vs future professional club vs. future amateur	SA	Height Mass SSK	10 m sprint 20 m sprint 40 m sprint Max anaerobic power CMJ Isokinetic strength† Estimated VO$_{2max}$	**Height:** Q1, Q2, Q3 > Q4 (professional) **Weight:** Q3 > Q4 (professional) **Max. anaerobic power:** Q1 and Q3 > Q4 (professional) **Strength:** Q1, Q2, Q3 > Q4 (professional) **Estimated VO$_{2max}$:** Q1 and Q2 > Q3 (professional)
Figueiredo et al. [93]	N = 159 U13 (11.0- 12.9 y) U15 (13.1-14.9 y) Non-elite club level	Late vs. average vs. early maturer	SA	Height Mass SSK Leg length	35 m slalom sprint Shuttle run (5 x 10 m) SJ CMJ Repeated sprints Yo-Yo test (Level 1)	**Mass:** early > on time > late maturers (U13&U15) **Height:** early > on time > late maturers (U13&U15) **Leg length:** early > on time> late maturers (U13&U15) **SSK:** early > on time > late maturers (U13) **SJ:** early > on time > late maturers (U15) **CMJ:** early > on time > late maturers (U15) **Yo-Yo test:** late > on time and early maturers (U13)
Figueiredo et al. [g] [68]	N = 159 U13 (11.0- 12.9 y) U15 (13.1-14.9 y) Elite to non-elite club level	Future youth elite vs. future non-elite vs. future drop out	SA	Height Mass SSK Leg length	35 m slalom sprint Shuttle run (5 x 10 m) SJ CMJ Repeated sprints Yo-Yo test (Level 1)	**Maturity:** elite > non-elite and drop out (U13, U15) **Mass:** elite > non-elite (U13); elite > drop out (U15) **Height:** elite > non-elite and drop out (U13, U15) **Leg length:** elite > non-elite and drop out (U13, U15) **CMJ:** elite > non-elite (U13); elite > drop out (U15) **35 m sprint with slalom:** elite > drop out (U13, U15); elite > non-elite (U13) **SJ:** elite > drop out (U13, U15); elite > non-elite (U13) **Shuttle run (5 x 10m):** elite > drop out (U13, U15); elite > non-elite (U15) **Repeated sprints:** elite > drop out (U13,U15); elite > non-elite (U15) **Yo-Yo test:** elite > non-elite and drop out (U13, U15)
Le Gall et al. [60]	N = 161 U14, U15, U16 National level	Future national team vs. future professional club vs. future amateur	SA	Height Mass SSK	10 m sprint 20 m sprint 40 m sprint Max anaerobic power CMJ	**Maturity:** amateur> professional and international (U14-U16) **Mass:** professional > amateur (U14) **Height:** International and professional > amateur (U14, U16) **Anaerobic power**: International and professional > amateur (U14, U16)

Study	N / Sample	Mat. comparison	Mat.	Anthropo.	Performance tests	Results
					Isokinetic strength[†] Estimated VO_{2max}	**Jump height:** international > amateur players (U14) **40 m sprint:** international players > amateur (U14)
Vaeyens et al. [95]	N = 232 U13, U14, U15, U16 Elite to non-elite club level	Early vs. on average vs. late maturer	SA	Height Mass SSK Limb girth Bone breadth	SLJ Flying 30 m sprint Shuttle run (5 x 10 m) VJ ESHR STR	**All anthropometry variables:** early > on time > late maturers (U13-U16) **SLJ & VJ:** early>on time>late maturers (U13) **Flying 30 m sprint & shuttle run:** early > on time > late maturers (U13 & U14) **ESHR:** early > on time > late maturers (U15, U16)
		Elite vs. sub elite vs. non-elite				**SSK:** Elite and sub elite < non-elite **SLJ:** Elite > non-elite (U13, U14, U15) **VJ:** Elite > non-elite (U13 and U15) **Flying 30 m sprint:** Elite > non-elite (U13, U14 and U15) **Shuttle run:** Elite > sub elite and non-elite (U13, U14,U15) **ESHR:** Elite and sub elite > non-elite (U13, U14); Elite > sub elite and non-elite (U15, U16) **STR:** Elite and sub elite > non-elite (U13, U14); Elite > sub elite (U15); Elite > non-elite (U16)
Malina et al. [96]	N = 69 U15 (13.2 to 15.1 y) Elite club level	Early vs. on average vs. later maturer	PH	Height Mass	30 m sprint CMJ Yo-Yo test (Level 1)	**Height:** PH5 > other PH **Mass:** PH5 > PH3 & PH4 > PH1 & PH2 **30 m sprint:** PH4 & PH5 > PH1 & PH2 **CMJ:** PH4 > PH2 & PH3 **Yo-Yo test:** PH2-PH5 > PH1
Hansen et al.[g] [97]	N = 110 U12 Elite and non-elite club level	Elite vs. non-elite	PH	Height Mass SSK	SLJ Isometric strength[¥]	**Height:** Elite > non-elite **Mass:** Elite > non-elite **SSK:** Elite < non-elite **SLJ:** Elite > non-elite **Isometric strength:** Elite > non-elite

Mat.: maturity; Anthropo.: anthropometric measurements; [†]Peak concentric torque of leg extensor and flexors at angular velocities 1.05 and 4.19 rad/s; [g] Longitudinal study over 2 years; [¥] leg extensor, trunk and grip; Q: quartiles of year; SA: Skeletal age; PH: Tanner stage of pubic hair; U: under (age category); N: sample size; SSK: sum of skinfold; CMJ: countermovement jump; SLJ: Standing long jump; SJ: squat jump; ESHR: endurance shuttle run; STR: shuttle tempo run

Table 2.2. Technical skills used in youth soccer to discriminate between early, on average and late maturers; elite, sub-elite and non-eltie players; and, skilled and unskilled players

Authors	Players	Groups	Mat.	Technical skills	Significant gradient (> = better; p > 0.05)
Figueiredo et al. [93]	N = 159 U13 (11.0- 12.9 y) U15 (13.1-14.9 y) Non-elite Club level	Late vs. average vs. early maturer	SA	Ball control (body) Dribbling Wall pass Shooting	**No significant differences**
Figueiredo et al. [68]	N = 159 U13 (11.0- 12.9 y) U15 (13.1-14.9 y) Elite to non-elite club level	Future elite vs. future non-elite vs. future drop out	SA	Ball control (body) Dribbling Wall pass Shooting	**Ball control:** elite > drop out (U13, U15) **Dribbling:** elite > non-elite and drop out (U13); elite > non-elite < drop out (U15) **Wall pass:** elite > non-elite > drop out (U15)
Vaeyens et al. [95]	N = 232 U13, U14, U15, U16 Elite to non-elite club level	Elite vs. sub elite vs. non-elite	SA	Ball control (body) Dribbling Lob pass Shooting	**Dribbling :** elite > non-elite (U13, U16); elite and sub-elite > non-elite (U14, U15) **Lob pass:** elite and sub-elite > non-elite (U13-15) **Ball control:** elite > non-elite (U13); elite and sub-elite > non-elite (U14, U15)
Malina et al. [98]	N = 69 U15 (13.2 to 15.1 y) Elite club level	Skilled vs. unskilled (5 levels)	PH (1 to 5)	Ball control (body) Ball control (head) Dribbling and passing Dribbling speed Passing Shooting	**No significant differences**
Malina et al. [99]	N = 69 U15 (13.2 to 15.1 y) Elite club level	Early vs. on average vs. later maturer	PH (1 to 5)	Ball control (body) Ball control (head) Dribbling and passing Dribbling Passing Shooting	**Dribbling and passing:** PH2, PH4 & PH5 > PH1

Mat.: maturity; SA: Skeletal age; PH: Tanner stage of pubic hair; U: under (age category); N: sample size

The wide spread of maturity status of individual players makes it very difficult to have confidence in biological age parity within competitive age group categories [100]. It can be observed from longitudinal [97, 101, 102] and cross sectional [60, 93, 95, 103, 104] data that changes in physiological performance are associated with growth. Given this information, the physical assessment of young players should be interpreted alongside maturational status to conduct a more objective talent identification process [52]. A body of literature [103, 105-107] intending to determine predictors of junior and youth selections in various sports is faced with important limitations because no maturity index was initially determined [108]. Initial classification between late, on average and early maturers within the same age category is a valuable method to ensure equitability and has been conducted in soccer studies [93, 95, 96]. Even though early maturation was not always associated with better performance [60], it was usually related to greater body size (i.e. height and weight) [93, 95, 96] and to superior explosive performance (vertical and standing long jump) [93, 95, 96], sprinting (30 m) [95, 96] , agility (shuttle run) [95] and endurance performance [95, 96] across different age groups (U13-U16 categories). Furthermore, when predictors of performance were determined, via multiple linear regression analysis, 50% of the variance in 30 m sprint time was explained by weight and maturity, 41% of the variance in the vertical jump by height and maturity and 21% of variance in aerobic performance by years of football and maturity [96]. Considering the athleticism and body composition of the population investigated, differences in weight between maturation statuses can be associated with greater muscle mass even though the latter was not directly assessed. Muscle volume and size have been found to be strongly related to maximal strength [109-111], power output [4, 111, 112] and jump performance [110, 111] in prepubescent and pubescent males. Also, qualitative changes of the muscle (i.e. contractile properties and length of myofibrils) during growth which favour greater force and power output have been reported (see Van Praagh and Dore [8] for review). Therefore, maturation status and anthropometric characteristics of youth soccer players should be measured and accounted for when strength and power abilities are interpreted (i.e. scaling and statistical control). In the literature reviewed it can be observed that less variation in aerobic capacity among pubertal boys occurred [93, 96]. Peak velocity of growth in VO_{2max} coincided with peak height velocity (PHV) in boys [113] and during this period, Tanner stages of puberty from

2 to 5 were represented [52]. For that reason, it is likely that maximal aerobic power differences are more present in the early stage of puberty (i.e. differences between Tanner stage 1 and 2-5) [96].

A multi-dimensional approach of talent identification should include a reliable battery of sport specific skills (e.g. dribbling, shooting, ball control, passing) in combination with physical, physiological and psychological tests [55]. Sport-specific skills have been used as predictors of success in soccer [55, 114] and other sports (i.e. tennis, handball, and field hockey) and were often more sensitive than physical and physiological parameters [106, 115, 116]. However, none of the above investigations determined the players' maturity status and it is possible that elite or better players were biologically more advanced than their counterparts. This may have three major influences on the measured technical skills. Firstly, mature players are likely to be older and therefore have more playing experience and time to develop the skill [71]. Secondly, they may be faster, stronger and more powerful [52] which may influence the results of technical drills where these components play a role (i.e. fast pace dribbling). Thirdly, by being more mature and older, it may result in greater neuromuscular control [117, 118]. Several authors have investigated the role of maturation on technical skills in youth soccer players (see Table 2.2) [93, 98, 99]. All tests administered in these studies assessed similar technical abilities: ball control, passing, dribbling and shooting (i.e. a closed skill environment; see Figueiredo et al. [93] for reliability on these tests). In summary, it was found that the number of playing years [93, 99] and maturity status [98, 99] were likely to affect these skills. Differences between age categories (i.e. U13 vs U15) were found, which seemed logical due to greater maturity and years of play [93]. The results of longitudinal data on the evolution of dribbling ability during growth [119] was found to be similar, players improving by 11-12% between 12-19 years of age with the most rapid increase between 12-14 and 16-17 years of age. Also, age, lean body mass and the number of hours of practice (specific and non-specific) were the factors observed as most important in contributing to dribbling performance. When players within the same category were grouped as early, average and late maturers [99], or by skilled level [98], mature players scored better in some of the technical skills (4 out of 6 skills) and were more represented in the highest two skill levels compared to the other three skill levels (78.6-85.7% vs. 35.7-50%). In addition, maturity status, height, mass and years of play explained 13% to 21% of different technical skills (i.e. dribbling with pass and ball control with body or head) [99] or a composite of

38

skills [98]. This suggests that within a relatively homogeneous sample of adolescent soccer players, players born early in the year will have more hours of experience and with advanced biological maturity status may be associated with slightly better technical performance. However, body size and maturity have a larger contribution to physiological performance than technical abilities [96]. While the ability of these tests to reproduce game like situations (i.e. validity) is still to be determined, their sensitivity to distinguish between elite and non-elite youth players as well as between future professional and non-professional players has been addressed, and is discussed in the following section.

Physical, physiological and technical characteristics of elite youth and future successful players

The comparison between elite and non-elite youth players and future successful or non-successful players (i.e. signing or not a professional contract) is of major interest to determine the keys to superior performance and future success. However, the aforementioned bias in maturity status created by the selection process needs to be taken into consideration, since biological age can be a confounding factor when physical and physiological characteristics of youth players are investigated. A retrospective study [68] reported that players, selected for an elite youth team after a two year follow-up from initial testing, were already more mature, heavier, taller, faster, more powerful and agile at the time of testing (U13 and U15) than players who remained at a non-elite level or dropped out. However, after maturity was statistically controlled for, elite and/or sub-elite players were found to be leaner (U12-U15 category) [95, 97], faster (U13, U14, U15 category) [95], more agile (U13-U15 category) [95], more powerful (U12-U15 category) [95, 97] and had greater aerobic power [95] than non-elite players. These differences were attributed to a advanced neuromuscular system in the elite players caused by a greater volume and intensity of training [97]. Therefore, body composition and physiological assessments can be considered sensitive to training and important to success in youth soccer and should be developed and monitored.

Becoming a professional player is the main goal of gifted young soccer players, and being at an elite youth level can be considered promising but does not guarantee success. In a retrospective study, Le Gall *et al.* [60] demonstrated, across three age categories (i.e. U14, U15, U16), superior physical (i.e. height, mass) and physiological characteristics (i.e.

speed, power) for players who were successful in attaining international or professional level compared to players who remained amateur, especially at the U14 category. These differences were magnified when position on the field was analyzed separately across the three age categories. Roescher et al. [102] also found that endurance development (as measured by an intermittent shuttle test) between 14 to 18 years of age was able to discriminate future professional players from amateur players. These results support the fact that speed, agility, power and endurance may not only be important qualities for youth success [95, 97] but also success at a later stage in the career and may be influenced by the position played. However, physiological test batteries have not been able to distinguish until later, both elite from sub-elite youth players (U15-U16) [95] and future professional from amateur (U17) [102] and were unable to differentiate future internationals (i.e. national team players) from future professionals (i.e. first national division players) [60]. Therefore, continuous monitoring should be conducted (i.e. longitudinal progress) and a multi-dimensional approach including cognitive-perceptive abilities [54, 58, 59] may be needed to differentiate national from club level players. This cognitive ability may not be detectable before the end of adolescence [120], indicating that selection should not occur beforehand.

Since timing and tempo of maturation largely influences the physical and physiological characteristics of young players, it can be expected that players from the first or second quartiles of a year will be physical and physiologically more advanced. A previous retrospective study reported that differences in physical and physiological characteristics within future professional players existed when players were placed in yearly quartiles [82]. Older players were taller, heavier, more powerful, stronger and had more endurance (see Table 2.1) but while disadvantaged physically at youth level, younger players in the programme had a better ratio to become successful (Q1 = 45.6% vs Q4 = 70%). Figure 2.2 illustrates the successful rate to become a professional player in a national academy. It is likely that these gifted younger players overcame these disadvantages by overcompensating in other areas of the game e.g. greater perseverance and motivation (i.e. "compensation phenomenon") [56]. If less mature but talented players are given the opportunity to remain in an elite academy and catch up in physical abilities, they have a good chance of becoming professional players [82]. They may also become more successful at the highest level as players born late after the cut-off date are expected to earn

systematically higher wages compared to their counterparts born earlier in the selection year [121].
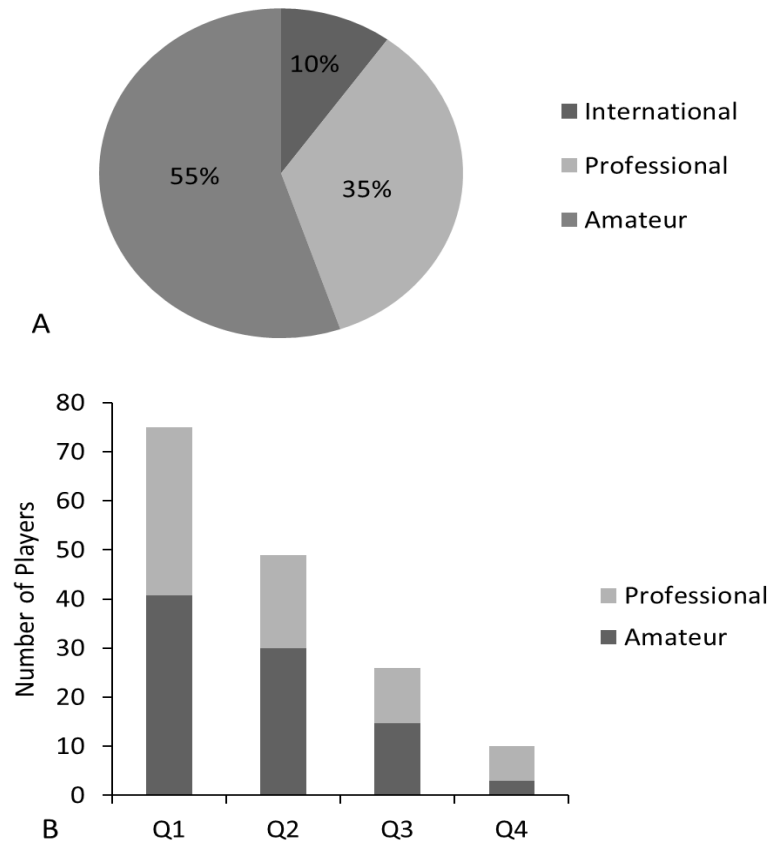
Figure 2.2. Successful rate of players achieving professional status in a soccer academy.
Figure 2.2A represents the rate (%) of players achieving professional, international or amateur status at senior level from the national French Academy (n = 161) [60]. Figure 2.2B illustrates the players' birth date distribution in Quartiles (Q1-Q4) and number of players achieving professional status in each Quartile from the same academy [82]

The predictors of playing level can be determined by quantifying the technical abilities of elite, sub-elite and non-elite youth players. After controlling for maturity, various technical tests (i.e. dribbling, lob pass, ball control with body) discriminated between current elite, sub-elite and non-elite players but only dribbling consistently discriminated ability across all age groups (i.e. U13-U16) [95]. This demonstrates that certain soccer-specific skills, especially dribbling, are more sensitive than other drills to detect differences in player level/ability and can detect future professional from amateur players as early as 14 years of age [114]. Furthermore, the sensitivity of technical skills assessment to differentiate level of performance increases with age (U13 vs U15-U16) [68,

41

95]. Therefore, technical skills should be included in talent identification process, but as the difference between levels tend to be more prominent towards U15-U16, early selection should be avoided and maturity accounted for. To determine progress of the young player, both physiological and technical skills should be monitored (i.e. responsiveness to training). Considering the differences in timing and tempo of maturation, coaching staff should not select players based on the short term outcome (i.e. youth competitions) but rather emphasise a long-term development approach. Playing position in particular, can be regarded as a choice that coaches need to make wisely when considering the career plan of a player.

Maturation status, physical and physiological characteristics as a determinant of playing position in youth soccer

Playing positions (e.g. defender, midfielder) require different physical and physiological characteristics at both junior and senior level [53]. Previous researchers investigating youth soccer have suggested a link between playing position, maturity, physical and physiological characteristics [65, 94, 96, 122]. Forwards and defenders were more mature than midfielders in U15 [96] and U16 [65] teams, and may well match each other in size, speed, strength and power where winning challenges is crucial. Aerobic fitness appeared to be influenced by training years rather than maturity [96], and therefore midfielders were found to be at an advantage in aerobic capacity [96]. This advantage may also be linked to the increased physical demands in match-play and training from a youth level [123]. In a wider age range of players (i.e. Senior and U18-U15) and a large sample (n = 241), this trend was found to be accentuated with the strikers being the leanest, most powerful (i.e. jump height), fastest and most agile [122]. On the other hand, in younger players (U14) and with a smaller sample (n = 70), no difference in physiological parameters were found between positions and only the forwards were smaller and lighter than the rest of the players [124]. These inconsistent results can be partly explained by differences in sample size and most importantly the players' age. Intuitively it makes sense that players are slowly tailored to a specific position. From a prospective point of view, it has been demonstrated that future professional players were superior to future amateur players in different physical and physiological parameters depending on the position played [60] (see Table 2.1), supporting the hypothesis that specific physical and physiological characteristics are required to be

successful in a playing position. Therefore, early or late maturation may affect the chance to be selected and play in certain positions. The RAE present over four world cups in the English National soccer team (1982-1998) was more pronounced in playing positions where stature, strength, power and speed were more important (first trimester of cut-off date: goalkeeper: 69%; defender: 51%; forward: 48%; midfielders: 44%) [84]. From the studies presented in the current review, only slalom dribbling could differentiate technical abilities amongst playing position at a youth level [98, 99, 119], and therefore tactical choice in youth soccer can be partly dictated by physical and physiological parameters and/or specific game sense, which is transferred to the senior years. From a competitive stand point, it is appealing to position a young player on the pitch where they are the most successful. However, it is possible that the early physical and physiological advantages may not transfer into adulthood and players may find themselves with a lack of ability to play elsewhere on the field. From a long-term player development approach, tactical sense and technical abilities should be developed in junior years across different positions and playing systems in order to reduce the likelihood of physical disadvantages associated with a certain position at the senior level.

Determination of biological maturity and controlling for its confounding effects

Since the birth date distribution and the importance of maturation on body size and physiological performance are shown to be an important influence in selection in youth soccer, there is a need to reconsider the theoretical question of age grouping and comparing young players on the sole principle that they are born in the same year. Previous reviews on RAE [64, 71] have offered some recommendations to the problem: 1) expansion of age group bandwidths to 15 to 21 months and rotation of cut-off dates across particular ages and constantly change group composition; 2) reduce bandwidth to 9 months to reduce potential age inequalities; 3) change cut-off dates by 3 months between seasons of competition to ensure players experience being in each quartile positions across their youth career; 4) implement player quotas for each quartile; and, 5) group players according to physical characteristics (i.e. height and weight). Also, competitive success at a young age should be deemphasised considering that players often get selected based on their physical and physiological attributes for immediate results (i.e. short term outcome vs. long-term benefits). These suggestions should be considered by sporting organisations and are beyond

43

the role of coaches and sport scientists. Coaches' awareness on RAE and the role of maturation on physiological abilities of youth soccer has been viewed as a solution [64, 71] and was previously discussed at length. However, coaches are faced with a selection of players and must have practical tools to interpret physical, physiological and technical testing. An estimation of biological maturity would appear to be the first step for fair and efficient selection of gifted players considering its importance in the game and confounding effect on the selection process.

Clinical determination of maturity status

Biological age, determined using either non-invasive or invasive measures, can give the coach and medical staff an accurate indication of the player's maturity and indicate timing and tempo of maturation compared to same age peers. It is also used to determine critical periods for training in terms of long-term development planning [100]. The most common clinical method to determine biological age traditionally uses plain X-ray of the left hand, wrist or knee and several methods to interpret these X-rays are available (i.e. Fels, Tanner-Whitehouse, Greulich and Pyle methods) [52]. Skeletal age is an indicator of physiological maturity since it provides a continuous indication of growth until maturity. This method has been used extensively in football institutes and academies to classify players according to their skeletal age compared with their chronological age [60, 65, 82, 100]. To determine early, on average or late maturation, chronological age is subtracted from skeletal age. A positive score indicates that skeletal age is in advance of chronological age, whereas a negative score indicates that skeletal age lags behind chronological age [65]. However, even though the amount of X-ray exposure is regarded as minimal (1 ± 2 mrad) [125], the cost and ethical issues of invasive measures need to be considered in non-clinical situations particularly if a long-term study on a large number of subjects is planned [100]. To overcome the X-ray exposure dilemma, recent studies [126, 127] have developed the use of magnetic resonance imaging to assess the biological age of youth soccer players. If this method has been found to be reliable, validated and proved to be successful, the costs of magnetic resonance imaging assessment are beyond most budgets and therefore other options need to be considered.

Physiological parameters such as dental age or sexual maturity revealed by secondary traits like pubic hair may be used as criteria to determine age grouping. Stages of

pubic hair development as described by Tanner [63] have been found to be consistent with skeletal maturity of youth soccer players [93]. However, the Tanner staging approach albeit non-invasive, is considered less preferable than X-ray for a number of reasons including reliability and child protection issues. In addition, financial funding and access to a physician may be limiting factors to use this method in a practical setting. Self-reporting using Tanner staging could be viewed as a substitute to the direct assessment as it is less intrusive and easy to use with large subject numbers [128]. Previous studies [128, 129], using self-assessment as a classification of maturity status, suggested positive links between sexual maturity and physical performance in boys. These results can be viewed as a good rationale for estimating biological maturity via self-assessment and highlight the importance of taking into consideration the maturity status of the players when physiological testing is conducted. This approach has also been found to have good concordance with physician assessment [129-131] and good reproducibility [129]. However, coaches and sport scientists need to keep in mind that clinical and the self-reporting method of Tanner staging may have some limitations and has also been observed as unreliable by other researchers [132-134].

Finally, stages of puberty can be estimated by measuring circulating androgen and/or growth hormones. Previous longitudinal [97] and cross sectional [104] studies have demonstrated that the acceleration and level of strength and power in pubescent soccer players is related to level of circulating androgen (i.e. testosterone, dehydroepiandrosterone) [97, 104] and insulin-like growth factor I [97]. Hormonal levels can either be measured by blood or saliva sampling techniques. Considering the ethical issues with blood sampling in children, saliva sampling offers a better alternative. Methodological considerations such as control of stress level (e.g. exercise) and contamination of food debris prior to sampling have to be addressed [104]. But despite its practicability, saliva measures of hormone levels are relatively expensive and require laboratory facilities to store and analyse samples. Therefore, non-invasive field based methods of maturity status have to be considered.

Non-invasive determination of maturity status

Several non-invasive maturity indicators with minimal physical and/or psychological risk have been developed. PHV (peak height velocity) has been widely used to determine

longitudinal changes in physical performance [52, 135, 136] and provides a common landmark to reflect the occurrence of other body dimension velocities within and between individuals. However, usually serial measurements for a number of years surrounding the occurrence of PHV are necessary and can only be used retrospectively. Using the known segmental growth patterns, a gender specific multiple-regression equation has been developed to predict maturity offset represented as years from PHV [137]. The prediction equations require measures of stature, trunk length, and leg length, as well as body mass and chronological age. Using these growth indicators, age from PHV was predicted within ± 1 year in 95% of cases in children from 4 years pre-PHV to 3 years post-PHV. Such an approach represents an excellent alternative when classification of youth players and interpretation of physical tests is being conducted [66, 73, 138] but has limitations with extremely short athletes for their age [139].

Alternatively, another method of using somatic growth is to express height in terms of the percentage of final predicted adult height using age, height, weight and mid-parent height [140, 141]. When parents' height is self-reported, values need to be adjusted with gender specific equations [142] for the tendency of individuals to overestimate height [143]. This predictive method has been used as a maturity indicator in studies of activity level [144], injury risk in youth football [91, 145] and has been validated against an established maker of biological maturity status (i.e. skeletal maturity), giving a concordance of 62% [146]. Using large sample sizes as reference values (age-specific means and standard deviations) [91, 147], the maturity status of players can be expressed as a *z*-score [148] and then interpreted to estimate maturity status: on time, z-score between -1.0 and +1.0; late, z-score below -1.0; early, z-score greater than +1.0 [146]. Specific team values can be used to calculate individual z-scores and determine the maturity status of players in relation to fellow team players. Two players might be of the same age and height, but one is closer to mature height than the other and therefore more mature. Hence, height as a sole measurement of maturity status can be misleading since it is confounded by variation in maturity status. This method has demonstrated to be sensitive enough to determine differences in anthropometric measures (i.e. weight and BMI) among boys of contrasting maturity status within the same age group [91]. Therefore, it could be of interest to determine if differences also exist in physical performance between players of contrasting maturity using this classification.

Tracking of weight/height using percentiles on growth curves can also be used as an indicator of the player development compared to normative data [65, 73, 96]. However, this method must be used with caution as a male player, for instance, might be in the low percentile in height because he is a late maturer or simply because he will never be tall in relation to the normative data. Also, only players of the same ethnicity should be compared to the normative data as it is known that some ethnic groups mature a lot sooner than others (e.g. Pacific Islanders) [52].

Controlling for the confounding effects of maturity

As discussed previously, maturity status and associated body size variables (i.e. mass, height, muscle volume) play an important role in strength and explosive performance. Therefore, data analysis needs to account or scale for these biological differences to determine the role of quantitative (i.e. body size) and qualitative (i.e. body tissue and structure) characteristics in performance [30]. According to Winter and Nevill [30], scaling has four uses: 1) to compare an individual against standards for the purpose of assessment; 2) to compare groups; 3) to explore possible relationship between physiological characteristics and performance; and, 4) in longitudinal studies that investigated the effects of growth or training. Considering these four points, scaling should be applied in youth soccer studies (e.g. elite vs non-elite) to account for body size. Traditionally, the ratio standard is used in scaling (e.g. power/body mass), but has been criticised due to spurious correlations, misinterpretation of the data and indirect conclusions resulting from this analysis [30-33, 35, 149]. Appropriate approaches include analysis of covariance (ANCOVA) and allometric modelling [30, 31, 33, 35, 149]. The assumed linear relationship for ANCOVA is not always present and the error about regression is not necessarily additive but might be multiplicative. When this is the case, allometric modelling must be used (i.e. power function ratio: $y = a \cdot x^b$) [30, 31, 33, 35, 149]. This form of scaling has been found to be more accurate than ratio scaling to distinguish physiological abilities of different populations [37, 38]. When field test measurements (e.g. jump height, speed) are used, power function ratio may not be the most appropriate [149], and maturity and body size variables should either be incorporated into the research design and/or statistical analysis (e.g. ANCOVA). ANCOVA was utilised in some studies summarised in Table 2.1 [60, 82, 95, 96] and 2.2 [95, 98, 99] with maturity status and/or body size

variables used as a covariate. Since the purpose of this section is only to present an overall picture of the relevant statistical methods, the readers should review the specific literature on the topic before conducting these analyses [30, 31, 33, 35, 149].

Conclusion and practical applications

Talent identification and selection of players is a necessary process but requires a considerable understanding of the game demands and as well as knowledge of human growth and maturation. The RAE is present in many sports but appears to be more present in sports such as soccer, where the number of participants and competitive level is high. Mature players are likely to dominate the game physically at youth level due to greater body size, strength, speed, power and endurance but will not necessarily maintain this advantage at senior level. Non-invasive methods for estimating maturity status may allow youth programs and coaches to interpret physical, physiological and technical testing data with a better understanding of human growth. Technically skilled yet less mature players may be overlooked in the selection process due to maturity associated limitations in their physical and functional capacities (i.e. smaller size, or less strength, power and speed). By ignoring the difference in maturity status, coaches may favour players who are more competitive at the time of selection but will reduce the chance to retain the players in the programme with the most potential. In addition, staff members should not base their tactical choice (i.e. playing position) solely on physical or physiological attributes, as these characteristics may not be transferred into the highest level. A long-term player development approach should aim to keep a large number of gifted players and provide them with the same opportunity and quality of training and competition since younger players are found to be as successful if not more when they are selected into a programme. In that sense, different national soccer federation (Scottish, Irish, Canadian Football Associations) have adopted the Long-term Player Development model created by Bayli [150]. As expressed by the RAE within the licensed players in a country, skewed birth date distribution is not only a product of the coaches selection process but also due to the "self-elimination" of youngsters. Therefore, young players should be encouraged to try the game without any pressure and training and competition may be adjusted to take into account physical size or biological maturity status. However, if such an approach is appealing, it should be kept in mind the psychological and social implications associated with asking

players to train or compete with older or younger peers. Early maturers may not be able to cope with the emotional or cognitive demands associated with competing with older athletes. Likewise, late maturers may perceive it as degrading to play with younger players and drop out of the sport anyway. Educational sessions dedicated to explaining the procedures and philosophy of such programmes to the players and parents may help overcome some of these issues.

Concerning the choice of physiological and technical assessment, the tests should simulate the demands of the sport (i.e. validity) and match the abilities of the young players in order to accurately select players and monitor specific training effects. The timing of testing is important, and unfortunately many tests to determine ability are only performed at the beginning of the season. Inter-season and intra-season variability are both important especially as players can increase substantially in size and weight over a single sporting season. In the case of soccer, sprinting (i.e. 30 to 40 meter sprints), leg power (i.e. vertical and horizontal jumps), agility (i.e. shuttle runs 5 x 10 meters), maximal anaerobic power, strength (i.e. isokinetic and isometric), endurance tests (YoYo intermittent recovery test level one; maximal aerobic speed test) and ball dribbling were found to discriminate youth elite from non-elite players and future successful from non-successful players (see Tables 2.1 and 2.2). As youth elite players undergo a larger training load compared to non-elite youth players, there seems to be specific adaptations, highlighting the importance that training methods must be matched to youth needs. Also, players with greater potential appear to be more successful in the future, supporting the argument that these physiological abilities need to be developed from a young age. However, very few of the tests described previously were able to discriminate elite from sub-elite players and future national team level from future professional club level players. It is likely that other parameters (e.g. decision making, anticipation) were also responsible for the differences in level of play and success. A comprehensive approach should be multidimensional, including psychological questionnaire/s (psycho-behavioural skills: goal setting, motivation, anxiety control), cognitive-perceptive assessment/s (e.g. computer game simulation), and open environment assessment/s (e.g. game like situation) in addition to the aforementioned testing battery. In addition, during scouting days, players could be organised according to individual size, birth date or maturity status so as comparisons are fair and equitable. It can also be considered that these differences occur only at a later stage in the career supporting the argument that retention in academy programs should be emphasised during puberty and

selection of players for a professional contract should be conducted after adolescence. Future research may investigate the role of maturation, physiological and technical abilities in real game situations (i.e. time motion analysis) in order to determine the importance of these parameters and establish to a greater extent the determinants for success at a youth and senior level.

Chapter 3: An integrative model of power development in youth football

Prelude

Besides establishing robust protocols to select players, appropriate training is crucial to the long-term player development process. Power is thought an essential physical characteristic in soccer but no systematic and evidence-based model exists to develop this attribute. Participation in deliberate practice, play and competition mostly dictate the success of a player's pathway and must be acknowledged before power training is integrated. Currently, generic long-term athlete development models do not prescribe any detailed training emphasis for power, regardless of taking a soccer player's participation model into account. Considering the dual components of power, training emphasis may be oriented toward velocity or force depending on their natural development during growth and maturation. Both the player's pathway and natural power development must be reviewed as they are likely to be contributing factors to a model of power training in youth soccer. Furthermore, a systematic analysis of training studies that have investigated power training in youth soccer would determine current best practice and limitations in this area. The information from the critique of the literature will guide training design variables such as training integration, block duration, session length and frequency, as well as training emphasis, mode, intensity and volume. The implementation of a model will ensure optimal integration of power training and its constituent parts (force and velocity) with clear training emphases throughout the developmental stages of a player.

Introduction

Soccer is an intermittent sport which requires different physiological components. The capacity to produce varied powerful actions during a 90-minute game is associated with high aerobic power (VO_{2max}) [53, 151]. However, the ability to produce a powerful single-bout effort is as important as aerobic power for success in soccer [152, 153]. Maximal power describes the highest level of power (work/time) achieved in muscular contractions [8]. In a sport setting, maximal power represents the greatest instantaneous power during a single movement performed with the goal of producing maximal velocity at take-off, release or impact [154, 155]. This includes movements such as sprinting, jumping, changing direction, throwing or kicking frequently occurring in soccer [151]. Many of these activities not only require maximal power but also a high rate of power development considering the short period spent on the ground to produce power, such as sprinting (< 100 ms) [156]. Various studies [60, 95, 97] have compared the physical capabilities of elite and non-elite youth players and future professional or non-professional players to determine the key to superior performance and future success. Elite and/or sub-elite players were found to be faster (U13-U15), more agile (U13-U15) and more powerful (U12-U15 category) than non-elite [95, 97], while, future international and professional players had superior explosive characteristics (i.e. speed, power) at youth level (U14-U16) than future amateur players [60]. These results support the fact that soccer-related, explosive activities requiring power may not only be important qualities at youth level [95, 97] but also at a later stage of a player's career [60]. Given the importance of maximal power for soccer performance [152, 153], particular attention to its continuous monitoring and progressive development from a young age should be fundamental to any player development program [157].

Recent frameworks have been proposed to develop specific athletic abilities related to power development such as the stretch-shortening cycle [158] or Olympic weightlifting [159] based on the generic long-term athlete development (LTAD) models [5, 159]. However, these models only pertained to a specific mode of training and did not follow a sport-specific model. When designing the model to develop a particular physical component in a sport, considerations must be given to various factors (e.g. hours and structure of training for a given age) to ensure its effectiveness. There might be numerous paths by which a player attains elite status, however researchers have detailed some specific

52

trends to excellence in soccer [69, 160-163] and therefore it is worthwhile to integrate the development of power within a given framework.

In addition, while players are involved in training for their sport, major morphological and neural changes are occurring due to growth and maturation [52]. These parameters can play an important role in the ability to adapt to a specific training stimulus as well as a specific training model [164-166]. Based on these premises, the theory of windows of trainability associated with natural accelerated development of a specific athletic characteristic (e.g. speed) has been articulated [5, 6], but the absence of evidence has resulted in conjecture and debate [1]. Considering the previous information, the primary purpose of this review is to propose a soccer-specific model of maximal leg power development throughout male youth soccer, defined as no older than 17 years old. The focus on the male player only is due to the difference in timing and tempo of maturation between the two genders, and their differences in physical and physiological characteristics from the onset of puberty [52]. First, a general framework leading to elite soccer and associated changes in maximal power capability during growth and maturation is provided. This section discusses both player pathway and natural development factors that are thought important to understand when designing a soccer-specific model. Second, training programs aimed at developing maximal power in athletic activities related to soccer are systematically reviewed to determine the most appropriate and effective training stimulus for a given age. This information is then translated into a proposed model for power development.

Conditioning factors to power development

The player pathway to excellence

Talent development or long-term player development aims at providing the most appropriate learning environment in the pursuit of excellence. In this respect, a stage-specific, individualized and balanced approach is desirable for optimal talent development [3]. The different stages within the developmental process to elite level are based on changes in the type and amount of involvement in sport activities such as deliberate play, deliberate practice, general and specific strength and conditioning [160]. Based on retrospective studies on team sport players [167-170], the developmental model of sport

participation (DMSP) was proposed [171]. The DMSP supports participation in a variety of sports during the sampling years (6-12 y), a reduced variety during the specializing (13-16 y) and substantial investment in the team sport after 16 years old.

In soccer, earlier engagement in competition and greater accumulated hours of deliberate practice of elite youth players compared to non-elite players tends to support the model of a radical early specialisation for elite soccer [69, 172]. Yet, greater soccer-related playful activity in the sampling years was related to: 1) players who progressed from an academy to professional status compared to the players released at 16 years old [172]; and, 2) players in more successful national teams (e.g. World Cup, Euro) [69]. This pattern of soccer activity during the sampling years of most successful players highlighted the need to engage early and find an appropriate balance between sport-specific deliberate practice and participation in sport-specific play in accordance with the DMSP model. However, an early diversification in different sport, and assumption of skill transference, articulated by the DMSP model was found to make no difference to the success rate of reaching professional status [69, 161, 172]. Consequently, the early phase of soccer involvement needs to be essentially sport-specific and has been referred as the "early engagement hypothesis" [160, 172]. This early focus has implications for the design and integration of optimal training methods for power development during this phase of a player's career.

The path to excellence in soccer follows the DMSP model in the specialisation and investment years as the involvement in other sport activities constantly decreases and the hours dedicated to soccer must be accumulated [69, 74, 161, 163, 172]. Future international and amateur players differed already in individual and total accumulated hours in soccer after six years (11 years old) and 10 years (15 years old) in the sport, respectively [173]. Further, a shift from playful to coach-led practice is needed during the specialisation years to create more successful professionals [69, 160]. The investment years are characterised by a reduction in individual practice and increase in team practice to focus on team success rather than individual player development [163]. This clear shift in soccer involvement and type of training methods should be reflected in the approach to develop maximal power.

Given the above information and the importance of maximal power for soccer performance, a specific model to develop this physical attribute in accordance with the participation model to reach excellence in soccer is needed. The LTAD model provides a holistic approach of how practice and play may be organised differently at various stages of athlete development [150, 174] and has been adopted by several national soccer

associations (e.g. Canada, New Zealand, Scotland, Eire, England). However, their model remains superficial and no specific framework to guide the training methods for maximal power in youth soccer with special reference to the participation model as well as the natural development of power during growth and maturation has been published to the knowledge of the authors.

The natural development and trainability of power

The natural development of maximal power during growth and maturation has been investigated via cross-sectional and longitudinal research designs. The limitation of the data from these studies is that they are derived from different laboratories employing dissimilar test apparatus and protocols, and using different subject cohorts (i.e. longitudinal vs. cross-sectional data), which does not allow inter-study comparisons and often complicates research in the area [175]. Much of what is known about maximal power is derived from large data sets (n > 100) collected on cycling ergometers.

Based on longitudinal data, increases of 102% (force-velocity test) [4] in optimal peak power (Pmax) can be expected between the age of 12 to 17 years old. In cross-sectional data, an increase of 67% between pre-teen (10 y) and teenagers (15 y) and up to 91% with adults (21 y) in adjusted Pmax to body mass was reported [15]. In addition, Martin et al. [176] demonstrated that in groups with similar anthropometric measures (lean leg volume, leg length, mass and percent body fat), Pmax increased by 17%, 20%, and 14% between 10 and 12, 12 and 14, and 14 and 16 year olds, respectively. It was also reported that the increase of Pmax in the prepubertal group was accompanied by a 9% increase of optimal velocity (velocity at Pmax), whereas the increase of Pmax in the pubertal and postpubertal groups was accompanied by an increase of optimal force (force at Pmax) by 12% and 13%, respectively. This indicates that, when anthropometric characteristics were controlled, Pmax still increased with age and was related to the improvement of one of its two components (i.e., optimal velocity or optimal force). To summarize the testing on cycle ergometers, it would seem that peak power or Pmax of young people continues to develop from childhood through adolescence and into early to middle adulthood when expressed in absolute terms, per unit of body mass, per unit of fat-free mass, per unit lean limb volume or even per unit lower limb muscle mass [175].

Similar trends in jumping and sprinting have been reported [157, 177, 178]. Absolute maximal anaerobic power performance during sprinting and jumping (indirect measure) improved by 148% and 121%, respectively, between 12 to 16 years old elite youth soccer players [177]. Improvement rates of 1-3% in 10-m and 30-m sprint and 7% in jump height per year can be expected between U12 and U16 soccer players [7, 157]. A 90% increase in peak power was observed between 11 and 14 years old when jumping on a force plate [178].

Both quantitative and qualitative factors seem to account for the development of maximal power capability in youth. Quantitative factors include increases in muscle mass, muscle cross-sectional area, and muscle fibre diameter, while qualitative factors include genetics, muscle metabolism, neural and hormonal influences [8]. The qualitative and quantitative factors responsible for maximal power development may act at different times or simultaneously during growth and maturation [8]. A change in rate of physical performance development during growth and maturation has been referred to as a "performance spurt" [6, 179]. Maximal power is the product of force and velocity and is defined and limited by the force-velocity relationship. Both factors are believed to change with growth and expected to influence maximal power [8]. Based on longitudinal data, several researchers [6, 135, 177, 179] have suggested an adolescent performance spurt in power development (i.e. vertical jump, indirect maximal anaerobic power) to begin about 1.5 years prior to PHV (~ 12.5 y) and peaks approximately around PHV to one year after PHV (~14-15 y), while the maximum velocity performance spurt in speed tests (shuttle run and plate tapping) tended to occur prior to 18 to 8 months prior to PHV (~12-13 y) [136, 179]. Similarly researchers using cross-sectional designs have shown an accelerated period of adaptation in jump performance at the age of 11-12 and post PHV (15+) [180, 181] as well as in cycling peak power around PHV (13-16 y) [182]. The first spike of accelerated period is likely to be related to motor control and skill acquisition, while the second phase of development could be attributed to changes in circulating testosterone leading to increased muscle mass and force production [97]. As demonstrated by others [4, 15, 176], velocity at peak power appeared to be the changing factor in peak power output prior to PHV while force at Pmax was a more important determinant during and post PHV. Figure 3.1 provides a theoretical outlook on the natural development of maximal power in reference to chronological age, PHV and participation model.

56
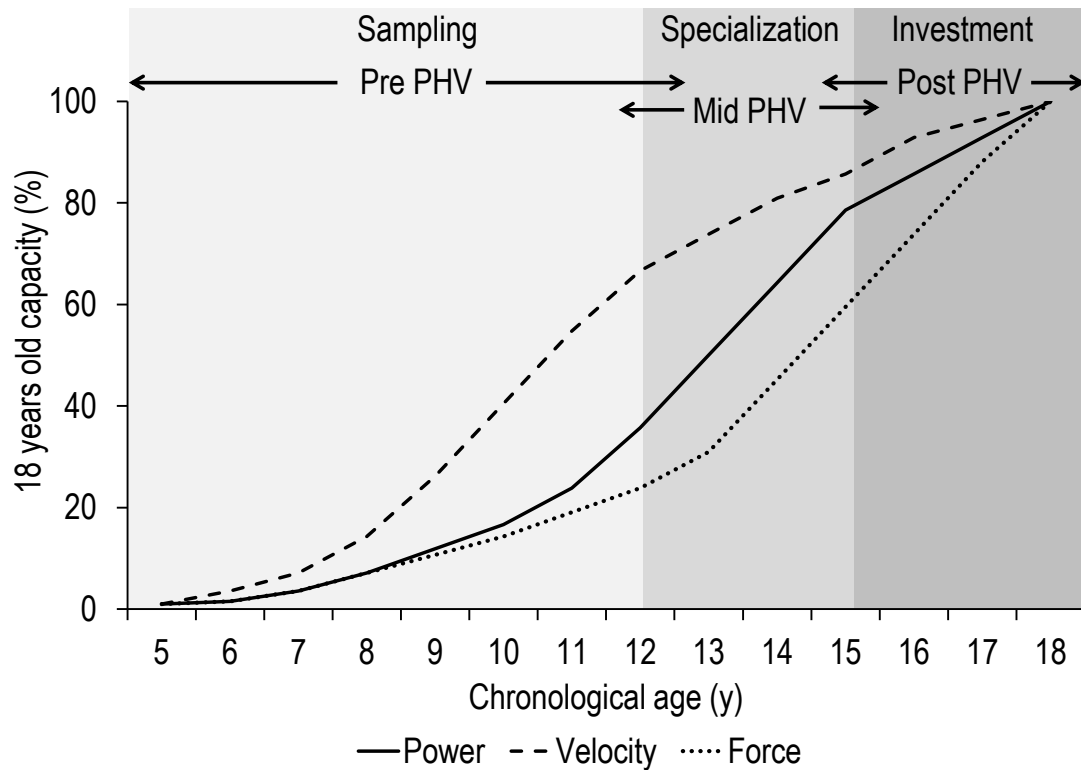
Figure 3.1. Theoretical model of power, velocity and force development in relation to chronological age, peak height velocity and throughout the soccer development pathway

Based on performance spurts of the different athletic characteristics, the concept of windows of trainability was introduced in the LTAD model to articulate optimum timing to train certain athletic characteristics during growth and maturation [5, 6]. However, there is a distinct lack of empirical evidence to support greater training adaptation during these phases as well as the risk of a ceiling effect on performance when these windows are missed [1]. The current LTAD model provides no indication of a 'window of trainability for power development during childhood [1]. This may be due because components of power (i.e. force and velocity) have their own separate windows of trainability included in the long-term athlete development model. The recent youth physical development model [2] provided some guidelines for power development but remained generic. Given the importance of muscular power in sport and its dual composite (i.e. force and velocity), it may be appropriate to consider the growth periods during which the training emphasis for maximal power should occur. Owing to the minimal number of longitudinal studies examining the interaction of growth, maturation and trainability on muscular power [7], it is difficult to identify a potential window of trainability to maximize power development.

57

Therefore a thorough review on the implementation of theoretical knowledge of power development and practical findings from training studies specific to youth soccer to increase power seems the most informative procedure to create a long term plan of power development in soccer players.

Systematic analysis of training methods to enhance power in youth soccer players

The aim of this systematic review is to provide a synopsis of the current practices used by youth soccer players to enhance power. To ensure clarity, players' developmental stage, playing level, the testing protocols and training modes were defined prior to the analysis of literature. The results are presented in themes relevant to training outcomes and simultaneously discussed in relation to previous research to highlight possible best practice and also the conjecture in the literature. The conclusions from this systematic analysis guide the model in the concluding section.

Definitions

Players' maturity and soccer developmental phase: In order to make this analysis relevant to the context of soccer development and relative to the growth and maturation, the players were categorised as to whether they were in their sampling years (6-12 y), specialisation years (13-15 y) and investment years (> 16 y). This classification, which has been used in another systematic review [166], corresponds approximately to the years prior to PHV (prepubescent), around PHV (mid pubescent) and post PHV (post pubescent) [52], providing both a soccer and developmental framework for further discussion.

 Playing level: Players were classified as elite, sub elite and recreational as stated in the studies. When the level was not stated clearly a threshold ≥ five sessions per week was used to categorise players as elite.

 Testing: A series of interrelated neuromuscular factors (e.g. mechanistic, metabolic, morphologic) contribute to maximal power production and development during growth and maturation [8, 175]. Generally, professionals take into consideration these different factors affecting maximal power when designing training programmes. However, they mostly rely on mechanical monitoring (e.g. force-velocity power profiling) and field-based measures (e.g. jump height and distance, sprint time) to monitor changes in maximal power as

58

underlying metabolic, morphological and neural factors can often not be measured due to methodological, financial and/or ethical issues. These field-based measures are also considered as some of the most functional and easy to administer tests that are representative of maximal power [177]. Given this information, only the over-ground assessments relevant to soccer and representing maximal power are the focus of further discussion.

Training mode: Neuromuscular training is defined as a supplemental training program such as resistance, stability, strength, plyometric or speed and agility training designed to enhance performance [183]. The term will be used throughout to address all types of supplemental training aiming to improve explosive performance. The types of training modes were further divided into power/plyometric training, speed training (including repeated sprints) and strength training for further analysis. When several methods of training were used (contrast or periodised from strength to power) they were classified as power/plyometric training.

Search strategies and inclusion criteria

The following electronic data bases were searched multiple times between September 1st, 2012 and October 31st, 2012: MEDLINE, EBSCO Host, Google Scholar, IngentaConnect, Ovid LWW, ProQuest Central, PubMed Central, ScienceDirect Journals, SPORTDiscus and Wiley InterScience between the years of 1950 and 2012. The following keywords were used in various combinations during the electronic searches: *soccer, athletes, youth, child, strength, force, power, jump, resistance, plyometrics, neuromuscular, training, in-season, off-season, athletic performance and development*. References were also identified from textbooks of sports science, strength, power and resistance training. The identified articles, manuscripts and theses reference sections were also scanned to identify further studies. The studies were required to be written in English. Initially, studies investigating the effect of neuromuscular training for 4-12 weeks on over ground power in male youth (8-17 y) were included in the initial screening phase (n = 41). Final selections were based on soccer-specific populations under the age of 18 years old (n =12).

Data analysis

To evaluate the magnitude of the dosage effects, percent change [(Post Xmean – Pre Xmean) ÷ Pre Xmean *100] was calculated for each dependent variable. Percent change is commonly used to estimate the magnitude of change in strength and power training studies [184]. However, percent change calculations do not take into account the variance of the change within and between groups, and therefore effect size (ES) calculations [(Post Xmean – Pre Xmean) ÷ PreSD] were included to account for variance by standardizing the training effects allowing for a more accurate comparison within and between training groups [185]. The standardised effect were classified as: trivial (< 0.2), small (0.2-0.6), moderate (0.6-1.2) and large (1.2-2.0), very large (2.0-4.0), extremely large (>4.0) [186]. The training effects were grouped as jump measures (countermovement jump, squat jump and drop jump), acceleration (0-15 sprint time) and maximal speed (20-40 sprint time). The results of the analysis were discussed according to different factors thought to influence training adaptations in youth soccer players such as soccer development stage/maturity, training duration, training sessions and training modes. To compare the influence of training mode and soccer development stage/maturity, the training effect was normalised by the number of training sessions (duration x frequency).

Table 3.1. Systematic review of training effects on explosive power actions in youth soccer players

Study	Age (y)	Soccer Dev. (Maturity marker)	Soccer level (y played)	Soccer training (h/w)	St-dur (w)	S/w	T-mode (integration)	# exerc.	Set x reps Contacts (Duration)	Test	Change (%)	ES
Michailidis et al. [187]	10.5 ± 0.5 (n =21)	Sampling y (Tanner 1)	Recreational (≥3)	6	12	2	Plyo (in-soccer T)	4	2-4 x 5-10 60-100 (20-25 min)	CMJ	↑27.3	3.00*
										SJ	↑24.5	2.00*
										DJ	↑15.6	1.75*
										HJ	↑5.3	0.10*
										MB5	↑19.2	3.17*
										10 m	↓4.9	-1.10*
										20 m	↓2.5	-0.29*
										30 m	↓3.1	-0.41*
Venturelli et al. [188]	G1: 11 ± 0.5 (n =9)	Sampling y (Tanner 1)	Elite (NR)	5.5	12	2	Speed (in-soccer T)	2	1 x 20 (30 min)	CMJ	↓0.4	-0.05
										SJ	↑5.5	0.04
										20 m	↓2.4	-0.90*
Venturelli et al. [188]	G2: 11 ± 0.5 (n = 9)	Sampling y (Tanner 1)	Elite (NR)	5.5	12	2	Plyo/ Coordination (in-soccer T)	5	1 x 10 (30 min)	CMJ	↑0.8	0.04
										SJ	↑2.0	0.09
										20 m	↓2.2	-0.62*
Diallo et al. [189]	12.3 ± 0.4 (n =10)	Sampling y. (Tanner 1-2)	Recreational (NR)	8	10	3	Plyo (in-soccer T)	NR	5 x 40-60 200-300 (NR)	CMJ	↑11.6	0.87**
										SJ	↑7.3	0.50*
										MB5	↑5.7	0.86**
										V20 m	↑2.7	1.50*
Buchheit et al. [190]	G1: 14.5 ± 0.5 (n =10)	Specialisation y (Tanner 3-4)	Elite (≥6)	~10.5	10	1	Repeated sprint (in-soccer T)	2	2-3 x 5-6 (15-20 min)	CMJ	↑7.0	0.43*
										10 m	↓1.5	-0.60
										30 m	↓2.1	-0.83*
Buchheit et al. [190]	G2: 14.5 ± 0.5 (n =10)	Specialisation y (Tanner 3-4)	Elite (≥6)	~10.5	10	1	Plyo/speed (in-soccer T)	4-6	4-6 x 4-6 (15-20 min)	CMJ	↑14.7	0.67*
										10 m	↓0.5	-0.08
										30 m	↓1.9	-0.39*

Study	Age (n)		Level		Weeks	Sessions	Training type		Sets x reps (duration)	Test	%	ES
Meylan et al. [191]	13.3 ± 0.6 (n =14)	Specialisation y	Recreational (2-4)	~5	8	2	Plyo (in-soccer T)	4	2-4 x 6-12 (20-25 min)	CMJ	↑7.5	0.59*
										SJ	↑1.3	0.10
										MB5	↑4.0	0.44
										RVJ	↑8.8	0.68*
										10 m	↓2.0	-0.57*
Wong et al.[192]	13.5 ± 0.7 (n =28)	Specialisation y	Elite (3-5)	6	12	2	Str/Pow (in-soccer T)	7-10	3 x 5-10 (NR)	CMJ	↑5.9	0.50***
										10 m	↓5.1	0.67***
										30 m	↓2.3	-0.32**
Christou et al. [49]	13.8 ± 0.4 (n =9)	Specialisation y (Tanner 3/4)	Recreational (3-6)	11.5	16	2	Str (pre-soccer T)	9	2-3 x 8-10 (45 min)	CMJ	↑23.1	4.19*
										SJ	↑30.1	5.36*
										MB5	↑14.8	2.29*
										10 m	↓3.2	-1.17
										20 m	↓2.6	-0.81*
Tonnessen et al. [193]	16.4 ± 0.9 (n = 10)	Investment y	Elite (NR)	14	10	1	Speed (isolated)	1	2-3 x 4-5 (~60min)	CMJ	↑7.7	0.69*
										20 m	↔	↔
										20 mFly	↓2.1	-0.45**
										40 m	↓1.2	-0.29**
Maio Alves et al. [194]	17.4 ± 0.6 (n =9)	Investment y	Elite (NR)	NR	6	1	CCT (in-soccer T)	3	3 x 6 (20-30 min)	CMJ	↑0.2	0.02
										SJ	↑12.7	0.85*
										5 m	↓9.2	-1.43*
										15 m	↓7.0	-1.80*
Maio Alves et al. [194]	17.4 ± 0.6 (n =8)	Investment y	Elite (NR)	NR	6	2	CCT (in-soccer T)	3	3 x 6 (20-30 min)	CMJ	↑2.4	0.19
										SJ	↑9.6	0.88*
										5 m	↓6.2	-1.75*
										15 m	↓3.1	-0.80*

Study	Age (n)	Investment	Level	St-Dur	# exerc	S/W	T-mode	No. Contacts	Reps	Measure	Change (%)	ES
Chelly et al. [195]	17.0 ± 0.3 (n =11)	Investment y (Tanner 5)	Elite (4-5)	10	8	2	Str (pre-soccer T)	1	4 x 2-7 (20 min)	CMJ SJ MB5 V5 m V40 m	↑7.4 ↑9.8 ↑4.7 ↑7.1 ↑11.9	0.63 0.78 1.67 1.40* 1.75*
Thomas et al. [196]	G1: 17.3 ± 0.4 (n =7)	Investment y	Elite (≥4)	~10	6	2	Plyo (in-soccer T)	NR	NR 80-120 (NR)	CMJ 5 m 10 m 15 m 20 m	↑7.8 ↑1.9 ↑1.1 ↓0.4 ↓1.0	1.00* 0.33 0.33 -0.14 -0.27
Thomas et al. [196]	G2: 17.3 ± 0.4 (n =5)	Investment y	Elite (≥4)	~10	6	2	Plyo (in-soccer T)	NR	NR 80-120 (NR)	CMJ 5 m 10 m 15 m 20 m	↑8.1 ↑0.9 ↔ ↓0.8 ↓0.6	0.80* 0.14 ↔ -0.18 -0.14
Gorostiaga et al. [197]	17.3 ± 0.5 (n =8)	Investment y	Elite (≥5)	~8.5	11	2	Str/Pow (in-soccer T)	5	2-4 x 2-8 (25-30 min)	CMJ 5 m 15 m	↑7.4 ↓1.0 ↔	1.31** -0.33 ↔

n = number of subjects; G1 = experimental group intervention 1; G2 = experimental group intervention 2; Adoles = adolescent; PrePub = pre puberty; Tanner = tanner staging system for Sexual Maturity; NR = not reported; St-Dur = study duration; S/W = number intervention sessions per week; T-mode = intervention training mode; Plyo = plyometric training; Str/Pow = strength and power training; InjPre = injury prevention training; CCT = complex and contrast training; # exerc. = number of exercises; Reps = repetitions; No. Contacts = number of plyometric jump contacts; CMJ = counter movement jump; SJ = squat jump; DJ = drop jump; MB5 = 5 unilateral multiple bounds; HJ = horizontal jump; RVJ = repeated vertical jump; 5m = 5 meter sprint time; V5m = 5 meter velocity; 10m = 10 meter sprint time; 15m = 15 meter sprint time; 20m = 20 meter sprint time; 20mfly = flying 20 meter sprint time (40m – 20m to determine top speed); V20m = 20 meter velocity; 30m = 30 meter sprint time; 40m = 40 meter sprint time; V40m = 40 meter velocity; Change (%) = percent change in performance following training; ES = effect size;↑ = increase from pre to post training; ↓ decrease from pre to post training; ↔ Indicates no change; * indicates significant (p ≤ 0.05) change following training; ** indicates significant (p ≤ 0.01) change following training; *** indicates significant (p ≤ 0.001) change following training.

Player characteristics

A total number of 293 youth soccer players, aged between 10-17 y, were investigated from which 178 participants followed a training program while 115 were used as a control. Four studies [187-189, 191] qualified the players as prepubescent while seven studies [49, 190, 192-197] investigated pubescent to post pubescent players. However, only six studies [49, 187-190, 195] actually measured the players' maturity status using Tanner staging. As various non-invasive methods are available to estimate maturity status [137, 141], future research should determine the maturity status of the players to enhance the applicability of the findings. Following the classification of chronological age and soccer developmental stage, players in three studies were in their sampling years (28%) [187-189], four in their specialisation years (40%) [49, 190-192] and five in their investment years (33%) [193-197]. All players in their investment years were considered as elite. Seventy-five percent of the studies [49, 190, 192] in the specialisation years were also conducted on elite/sub-elite players and only one study [188] conducted in the sampling years considered players as elite. Weekly playing time was 5.5 to 8 hours, 5 to 11.5 hours and 9 to 14 hours for training groups in sampling, specialisation and investment years, respectively. Despite the approximation in the reporting of playing level and weekly playing time, the current literature reviewed confirmed the DMSP model of greater specialisation and increased number of soccer hours with age [171].

None of the players had any history of systematic training, despite recommendations in paediatric sports to engage early in systematic neuromuscular training based on the high degree of neuroplasticity prior to the onset of puberty [183, 198, 199]. The pre-pubescent modification of neural activation may determine the phenotypic and contractile properties of the motor unit, which is crucial for future explosive performance in adulthood [200]. It also provides greater time to assimilate training technique and training load [158, 159]. Following maturation, young adults' cortico-motor plasticity and potential to assimilate new skills may be strongly diminished [201-203]. A recent meta-analysis [164] supported these recommendations as prepubertal children (<12-13 years old) were found to be more responsive to neuromuscular training than adolescents in developing athletic performance which required maximal power (i.e. combined effect on jumping, sprinting, and throwing).

After normalisation of the training effect of the intervention analysed (% change per session), the training dose-response for jump height enhancement became greater with maturation (sampling y: 0.42 ± 0.43%; specialisation y: 0.65 ± 0.43%; investment y: 0.67 ± 0.43%). The training dose-response for acceleration (sampling y: -0.20 one study; specialisation y: -0.13 ± 0.06%; investment y: -0.19 ± 0.46%) and maximal speed (sampling y: -0.11 ± 0.02%; specialisation y: -0.14 ± 0.06%; investment y: -0.09 ± 0.08%) remained unclear between the maturity groups. These results are somewhat contradictory to others [164], who found that prepubescents had better response to neuromuscular training to enhance athletic performance. The greater adaptations in jump height in the specialisation and investment years could be attributed to physiological changes occurring with growth and maturation but also to the greater vertical component of the intervention in these studies (Table 3.1). To investigate further the question of trainability during youth, the dose-response to a given training program should be compared across different maturity groups [204]. A few studies have investigated this problem [43, 45, 205] but failed to quantify change in maximal power. Therefore, there is still controversy on any specific windows of power trainability during growth and maturation.

Training block duration and session frequency

The training programs varied in duration from 6 to 16 weeks (mean 10 ± 2.8 weeks) with a mean training frequency of 2.0 ± 0.6 sessions per week. When only one training session was implemented per week [190, 193, 194], the players were elite (> 10h/week soccer training), suggesting that a time limiting factor in relation to soccer practice could be an issue in highly trained youth players. In recent reviews, it was reported that training duration and frequency were important factors for strength [165] and speed [166] improvement. The effect of study duration was analysed by splitting the interventions into lengths of 6-8 weeks (6 interventions; 6.7 ± 1.0 weeks) and 10-16 weeks (10 interventions; 11.5 ± 1.8 weeks). Both training durations had a small to moderate effect on jump height (6.9 ± 3.9% vs. 10.0 ± 7.7%; ES: 0.59 ± 0.34 vs. 1.00 ± 0.96), acceleration (-2.3 ± 3.7% vs. -1.7 ± 2.4%; ES: -0.53 ± 0.80 vs. -0.35 ± 0.48) and maximal speed (-0.8 ± 0.3% vs. -2.0 ± 0.8%; ES: -0.21 ± 0.28 vs. -0.48 ± 0.28). The difference in effect between the two clusters of intervention durations was small in jump height and maximal speed and unclear for acceleration. The effect of total training sessions was also analysed. The interventions were

divided into 6-16 sessions (9 interventions; 11.6 ± 3.1 sessions) and 22-32 sessions (7 interventions; 25.7 ± 3.7 sessions) for analysis (Figure 3.2). The effect of session number was clearer than total duration and needs to be considered in program design. The lack of variation in training frequency in the interventions reviewed did not allow comparisons, but previous studies in youth [206] and adults [184] have shown the greater power improvement with an increase in training frequency. In conclusion, it seemed that 6 to 16 sessions was found to have a small to moderate effect on jump and sprint performance in players with no systematic neuromuscular training history. The initial high dose-response to neuromuscular training is of interest for coaches dealing with young players as they could allocate more training time to technical/tactical skills. A progressive increase in weekly sessions from 1-2 to 2-3 would be recommended once the first few training blocks have been introduced and the first phases of development have been completed since trained young athletes do require greater training stimulus than players with no neuromuscular training history as per sample reviewed [164].
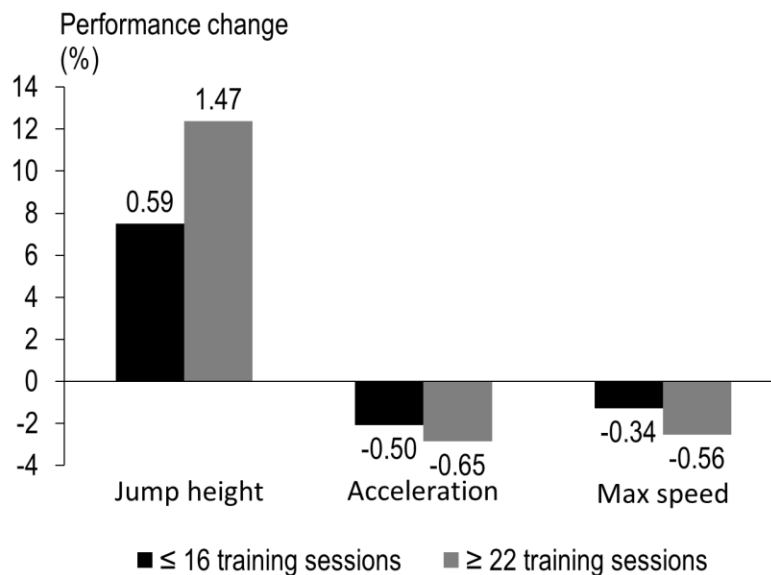
Figure 3.2. Change in performance (%) and effect sizes (top of each bar) following neuromuscular training categorised by number of training sessions (duration x frequency) of the course of the program.

Training mode

The specific distribution of training mode across the 16 interventions is presented in Table 3.1. Briefly, plyometrics was the most popular method of training. On several occasions, combined methods of training were used (e.g. contrast training). All training and control groups continued their regular soccer activity during the intervention period. As described previously, the training programs were split into plyometric/power (10 interventions), speed (4 interventions) and strength (2 interventions). By normalising the effect of training mode [change (%)/number training sessions] both strength (0.68 ± 0.20%/session) and plyometric/power (0.61 ± 1.18%/session) had similar effects on jump height, which was greater than speed training (0.43 ± 0.59%/contact). Given the vertical nature of the strength and plyometric/power programs, the results were to be expected according to the concept of training specificity [207]. The comparison of training mode effect on acceleration and maximal velocity was problematic. Acceleration time (0-10 m) was measured only in one study after speed [190] and strength training [49] and maximal speed (20-40 m) was included as an assessment in one strength study only [49]. As 80% of the sprints in soccer are 15 meters or shorter [208], it is somehow surprising that studies with the purpose of improving speed in soccer players would not include systematically both acceleration and maximal speed assessment in their testing battery.

The non-significant increase in power of the control group from the studies presented in Table 3.1 indicated that habitual soccer practice alone did not provide a sufficient stimulus to improve power production as compared to an additional neuromuscular training program. Christou et al. [49] demonstrated that after a period of 16 weeks, leg strength in the soccer group (33%) increased more than a non-active group (17%), but less than the strength group (59%). Similarly, a 2-year longitudinal study on 13-17 years old soccer players [7] demonstrated a significantly greater gain in strength (56-250%) and reduction in 30 m sprint time (4-6%) in players following a supplemental strength program (two session/week) compared to players only participating in soccer practice. Soccer may cause an additional increase to the natural development in leg strength, power and speed over the course of the season [7, 49, 157]. This enhancement could be viewed by coaches as significant but the literature reviewed clearly highlighted that an additional neuromuscular training program would accelerate the development of strength and speed and arguably power.

To inform the practitioner on a periodised plan, a further analysis to investigate the effect of different training methods during a specific developmental phase would have been valuable. However, the current sample of interventions was too narrow to arrive at any definitive conclusions. It was interesting to note that the four training programs from the two training studies in the sampling years were speed, coordination and plyometric training. In this sense, previous models of youth training have recommended training methods that stimulate inter-muscular coordination, movement efficiency and movement velocity (e.g. stride frequency) prior to puberty [198]. Further, Rumpf et al. [166] reported that plyometric training may be the most effective training method to enhance sprinting performance pre and around peak height velocity. As plyometrics is mostly associated with neural adaptations and increasing rate of power development and movement velocity [209], these findings support the previous model to enhance muscle power prior to puberty. But beyond training gain, it is important to consider long-term development and appropriate technique. Therefore, introduction of fundamental movement competency should be a pre-requisite to plyometric training to ensure a sufficient level of strength and correct technique [158].

As the players moved into the specialisation years, the training mode became more diversified with no specific trend. When strength training was implemented [49, 192], progressive loading was used. In the investment years, 50% of the interventions [194, 195, 197] had an element of heavy lifting (≥80% 1RM) to stimulate strength gains. The change in training mode across the development of soccer seems to be driven by the natural development of power. At the onset of puberty, a shift in the dominant factor responsible for power development has previously been demonstrated [4, 15, 176]. Velocity was found to be the variable responsible for increased power output prior to puberty, but as puberty begins, power output enhancement was associated with an increase in force production for an unchanged optimal velocity [4, 15, 176]. Increases in circulating testosterone and growth hormones [97], muscle mass [25], and motor unit activation [200] are all changes that occur from Mid-PHV and may be responsible for the increase and greater role of force in power output [8]. These physiological changes also seem to lead to greater strength gains after strength training in mid PHV and post PHV subjects compared to pre PHV children [165]. Complex training (mixture of strength and plyometric training) was also found to be the most efficient method to develop sprinting performance in post PHV [166]. Therefore, it seems that training emphasis and loading parameters should evolve during the player's

development to mirror the change in the relative contribution of force and velocity to maximal power production as well as the dose-response to training.

Session duration and integration

The training session durations ranged from 15 to 60 minutes (Table 3.1). Thirteen interventions were integrated into regular soccer training whereas two interventions were conducted just before soccer training and one intervention was completely independent of soccer as presented in Table 3.1. The integration of neuromuscular training in a soccer environment can be challenging, as it should not prevent technical and tactical development of the players. In this sense, interventions [187-192, 194, 196, 197] integrated into soccer practice were 30 minutes or less, straight after the warm-up. When the training was conducted on a separate day or prior to practice [49, 193, 195], more time was dedicated to the specific neuromuscular training (45-60 min), which demonstrated that greater volume could be conducted with soccer players. The strength and conditioner needs to be aware of the possible time constraint and should construct programs with this limitation in mind. When the training was conducted on a different day [193], only one session per week was possible, raising the issue of players' accessibility outside of soccer practice. The players in this study were already training 14 h/week already and allocating more time to training would seem challenging. To address this issue, the two studies focussing on strength training [49, 195] were conducted just before soccer practice. This may have been organised because of players' availability and also the difficulty to set-up appropriate equipment for strength training on the field The main concern with the latter approach and the integrated approach is the risk of training interference. The training interventions did not have a negative effect on aerobic capacity [187, 192, 197] and repeated sprint ability [190]. However, as soccer is a sport highly aerobic in nature [210], soccer practice within the same session or straight after power training may reduce the training adaptations required to improve muscle power [211]. It would be recommended to conduct independent sessions to improve power when possible, or integrate it in light and short soccer practice.

The volume of a session is characterised by the total amount of work performed in a training session and is represented by the number of exercises, sets, repetitions and intensity/load [184]. Typically plyometric training volume is defined as the number of ground contacts and intensity of the drills. The number of exercises during a session varied between 1 and 10 since the interventions investigated the effect a specific exercise (e.g. back squat, sprints) to a more varied training stimulus (e.g. complex training or various plyometric drills). Sets fluctuated between one and six with a number of repetitions between 2 to 12 (see Table 3.1). The plyometric intervention of Diallo et al. [189] could be considered high in volume (200-300 ground contacts) considering the volume in the other plyometric interventions (60-120 ground contacts). The latter volume has been recommended after meta-analysis in adult populations [212, 213].

Training intensity is an important training factor to induce improvement in explosive performance in young athletes [164]. The exercise intensities in the interventions reviewed were broad and dependent on the training adaptations targeted and players' maturity. Pre PHV players all performed low to moderate plyometric training with a progressive increase in intensity [187-189]. With Mid to Post PHV players, external load was used at about 30-40% of 1RM for power training [197] and was between 75-90% 1RM for strength gains [49, 192, 194, 195]. However, only three studies on post pubescent players [49, 194, 195] conducted 1RM testing on each exercise to accurately prescribe loading parameters, showing the difficulties of conducting such tests on young soccer players. The loading parameters reported above are similar to recent guidelines on youth resistance training [214]. As recommended, progressive loading was also used and two studies included a 2-4 weeks training block prior to the intervention to familiarise the players [49, 194]. In addition to progressive loading, one may consider greater movement complexity as a loading parameter to enhance functional power production. While difficult to apply and control in a short training study, movement based periodization should be integrated in the player's development to optimise neuromuscular training adaptations [158, 159, 215].

The exercise progression for power development in youth soccer players should consider the multi-planar and unilateral nature of most on field movement requirements such as sprinting, change of direction or header challenges. While speed training is very

specific, both plyometric/power and strength programming often aim to enhance maximal power of different movements. Several interventions were only focussed on vertical plane of motion [49, 192, 195-197] or were vertical dominant [187, 189, 194] only one plyometric intervention provided an equal vertical and horizontal stimulus [191]. Recent reviews on the topic [207, 213] have suggested that both strength and plyometric training should include horizontal and vertical movements to enhance vertical and horizontal power. The poor transference of maximal vertical strength improvement (20-50%) into sprint performance (2-3%) in several of the youth studies reviewed [49, 195] and in adults [216] support the need for training programs which include multi-directional unilateral force production.

Evidence-based model of power development in youth soccer

Based on the present literature reviewed, the creation of a model for power development in youth soccer must take into consideration a number of training design parameters. Natural power development and the player pathway should underpin the model. The natural power development factor guides training variables such as training emphasis, mode, intensity, and volume while the player's pathway influences power training integration, power training session duration, frequency and blocks. Although a number of publications have suggested different models for power development [198, 217] and related training mode [158, 159], it was deemed necessary to formalise a more comprehensive progression model (Figure 3.3), which corresponds both with the player's pathway and natural power development. It is intended that this progression model will provide coaches with a more strategic approach to develop power in youth soccer players. Specifically, this model is designed to give coaches clear and simple guidelines to follow based on scientific theory and evidence, without being overly prescriptive to allow situation specific needs. It is important to make clear that the model is designed for players who enter the soccer pathway at a young age, and that anyone entering at an older age should still complete some of the initial elements of the previous phases. Regardless of player's age, a child must develop functional movement pattern before attempting more complex drills and heavier loads [158, 159]. The model proposes that players progress from one stage to another according to the player's pathway and training emphasis periods, with the assumption of mastery at the previous stage. Owing the potential differences in maturity and motor

71

learning competency within an age bracket, coaches should use these guidelines with an awareness of individual variability in mind. Regular assessment of movement competency and power ability is necessary to adjust players program and allow them to progress individually. Finally, it should also be highlighted that the model has been based on the interpretation of available scientific research, but longitudinal empirical research is required to establish its effectiveness.

Investment years: (16⁺ years old)

PPF		NDF		
			Primary focus	**Secondary focus**
Integration:	isolated & integrated	Emphasis:	power	max force
Session duration:	20-60 min	Mode	SS plyo & contrast/OL	FMP resisted
Session frequency:	2-3/week	Intensity:	SK ecc & 0-30% 1RM	1-6 RM
Block duration	4-10 weeks	Volume:	3-6 x 1-6 reps	3-6 x 1-6 reps

⬆

Specialization years (13-15 years old)

PPF		NDF		
			Primary focus	**Secondary focus**
Integration:	isolated & integrated	Emphasis:	force base	RPD/velocity
Session duration:	20-40 min	Mode	FMP resisted	plyo & OL
Session frequency:	2-3/week	Intensity:	6-10 RM	high ecc & 0-30% 1RM
Block duration	4-6 weeks	Volume:	3-4 x 6-10 reps	3-4 x 4-8 reps

⬆

Sampling years: phase 2 (9-12 years old)

PPF		NDF		
			Primary focus	**Secondary focus**
Integration:	integrated in WU	Emphasis:	velocity/RPD	force-endurance
Session duration:	15-20 min	Mode	speed & light plyo	FMP
Session frequency:	1-2/week	Intensity:	BW & mod ecc	BW & light load
Block duration	2-3 weeks	Volume:	1-3 x 10-12 reps	1-3 x 10-15 reps

⬆

Sampling years: phase 1 (5-8 years old)

PPF		NDF		
			Primary focus	**Secondary focus**
Integration:	integrated in WU	Emphasis:	velocity	ABC
Session duration:	10-15 min	Mode	speed & light plyo	games
Session frequency:	1-2/week	Intensity:	BW & low ecc	BW
Block duration	1-2 weeks	Volume:	1-2 x 6-8 reps	1-2 x 8-10 reps

Figure 3.3. Evidence-based power development model of youth soccer players.
PPF: player's pathway factors; NDF: natural development factors; reps: repetition; BW: body weight; reps: repetition; ecc: eccentric; FMP: fundamental movement pattern; ABC: agility, balance and coordination; 1RM: one repetition maximum; RPD: rate of power development; OL: Olympic lifts; SS: sport specific; SK: shock; WU: warm-up

Sampling years

The sampling years can be divided into two phases considering that this stage encompasses age 5-12 years old and that both the mental focus and movement competency change extensively during this period [52]. In the first phase (5-8 years old children), the main objective is to develop fundamental movement skills (FMS) such as agility, balance and coordination with a high velocity component as well as introducing fundamental movement pattern (FMP) requiring triple extension at the ankles, knees and hips (e.g. squatting, lunging). No training studies in youth soccer have investigated this age bracket, but previous research has demonstrated the efficiency of neuromuscular training in general pediatric population of this age [218, 219]. To incorporate the concept of early engagement and deliberate play activities of the player's pathway, these exercises should be incorporated into games or deliberate play activities and not take up more than 10-15 minutes per session twice per week with a variation of exercises every two weeks. Training intensity and volume should be low enough to avoid muscle soreness. As the player gets older throughout the season, session frequency should be progressed from one to two sessions per week to ensure optimal training adaptations [206, 219]. This approach should eliminate the boredom that can be displayed by children who inherently dislike monotonous forms of training [220].

The second phase (9-12 years olds) should follow the same principles as phase one in terms of training integration, frequency and emphasis on movement velocity, agility, balance, coordination and FMP's. However, the training duration can be extended to up to 20 minutes per session including 1-3 sets of each exercise over a period of 3-4 weeks before exercises need to be modified. More intense exercise such as running, skipping, hopping, including a range of vertical and horizontal standing jumps can be introduced [215] but the plyometric load should rarely exceed 100 ground contacts when the preloading is substantially greater than natural stretch-shortening cycle occurring in normal practice [221]. In order for a child to minimize injury and maximize explosive training, it is suggested that they must display correct landing mechanics, including a heel-toe landing, supporting flexion at the triple extension sites, and avoid excessive valgus knee displacement [158]. This movement competency is developed by controlling the natural increases in body mass and light resistance FMP, which also serves as a base for future strength training [158].

Specialisation years

With maturation of the central nervous system [52] and the increase in circulating testosterone and growth hormones [97], muscle mass [25], and motor unit activation [200] with the onset of puberty, the primary focus during the specialisation years must be to increase the force level while maintaining a high velocity and rate of force development capability [198]. In support of this theoretical approach, researchers [7] have shown that the strength gains were higher in 13-15 year olds than 16-19 years olds with (290-312% vs. 101-123%) or without (59-62% vs. 21-50%) a strength training program. The strength program should be built on the exercises introduced in the previous phases with an increase in loading and movement complexity. Loads should be prescribed in %1RM where possible (60-80% 1RM) for 6-10 reps over 3-4 sets [214] or otherwise prescribed in RM for a given number of repetition. A strength/force base is crucial prior to maximal force training, which should be introduced towards the end of the specialisation phase and this maximal training representing one of the foundation pillars to maximal power output [217, 222].

In addition to the force base training, the introduction and development of Olympic lifting technique is warranted at this stage as it will provide an additional tool at a later stage to develop a powerful triple extension [159]. Plyometric progression should be continued with the introduction of obstacle and box jumps containing multi-planar components and fast ground contact times (<250 ms) representative of athletic performance and developing rate of power development [158]. The number of contacts over reaching regular stretch-shortening cycle (i.e. running, sprinting) can be increased to up to 190 ground contact/session depending on the exercises intensity and the players training history [221]. Both force and velocity/rate of power development training must be integrated into the soccer practice as much as times allows, preferably into sport-specific drills after the warm-up. As the soccer-specific involvement of these players increases and their daily schedule accommodates training demands, the neuromuscular training can also be conducted in isolation. As players adapt to training the training stimulus, progressive overload can be done by increasing intra-session load and then move from two to three sessions [184].

At this stage, adolescent players are entering young adulthood and sometimes train with adults. It is important not to consider these players as fully developed and often a reduced volume of training compared to senior players is recommended. Different modes of training can be used during this stage to increase maximal power and rate of power development in a periodised manner. Enhancing maximal strength is a vital consideration when designing training programmes that maximize the long-term development of maximal power [217, 223] as it is related to better improvement in sprint performance compared to soccer alone [7]. The maximal strength training should be periodised in alternation with plyometric and Olympic lifting or a combination with these training modes (complex and contrast training) [217]. The intensity in these blocks should be fluctuating between one RM to six RM over 4-6 sets [214].

Plyometric training needs to become sport-specific where movements on the field are being replicated with a shock or quick response to the eccentric load. This may include unilateral horizontal and lateral bounding as well as depth jumps. Players should be introduced to these exercises at a low intensity, gradually intensifying the stretch load [158]. The stretch load should not be increased to an intensity that promotes inhibitory protective strategy that reduces reflex activation and rate of power development [224]. At this stage, training undulation becomes crucial as fatigue induced by this type of high intensity training needs to be monitored closely [225]. Usually, players are offered a professional contract as they exit the academy system and a greater number of training units per week can be planned, which should allow power training in isolation more often than integrated into football training. To effectively enhance power, a minimum of two sessions per week is recommended [184], unless a heavy block of conditioning training is planned or several games are being played within a short period of time. In this case, power training must be reduced to allow proper recovery.

Summary

Currently, the numerous training interventions to improve power in youth soccer do not fall within a long-term model due to the limitations associated with scientific research and methodological design. However, this systematic review of literature has noted some trends

in terms of training modes and loading parameters throughout the developmental stages. It also provided guidelines regarding the effect of block duration and number of training sessions. This information guided the development of an evidence-based model of power development in youth soccer. The effect of different training modes during a developmental phase and the influence of maturity status on training adaptations to a specific training design are still unclear. Consequently, the training mode progression from our model relied on the evidence provided by player's pathway, natural power development and guidelines outlined previously. As player's development is dynamic and longitudinal in nature, the change in power and its components should be monitored over several years with a consistent testing battery to provide additional information to short-term interventions. Both the effect of maturation and sport-specific training on power development needs to be investigated while the inclusion of training intervention on players could further disentangle the effect of sport-specific training and additional neuromuscular training on power development.

Such a long-term approach should ensure the optimal integration of power training and its constituent parts (force and velocity) via clear training emphases throughout the player developmental stages. The specific soccer model can serve as a template for other team sports where power is a key element to athleticism. During the early phase of engagement into the sport, a major focus on velocity of movement and fundamental movement patterns is necessary to exploit the natural development of velocity capability and develop sound lifting technique necessary in the later developmental stages. Given the fact that children of this age are very playful and need extensive technical development, exercises should be integrated as much as possible into the regular practice. A qualitative approach is recommended without overwhelming the player with technical feedback. At the onset of puberty, a strong emphasis must be placed on force development via increasing loading /intensity and movement progressions, while maintaining an ability to produce high velocity movement and rate of power development. Training should still be integrated in practice where possible but can also be introduced in isolation. The investment years are dedicated to power training with a concurrent emphasis on developing maximal force. As maximal training intensity is reached, careful periodization and monitoring of fatigue becomes an integral element of training design. The current model is based on a movement competency philosophy, which focuses on quality before quantity. Players, regardless of age, should not be introduced to more complex movement or additional loads before

mastery has been demonstrated in the earlier stages. Because of the nature of team sport, the coach must be aware that individual differences may occur, and accommodate for players who are progressing faster or slower across the exercise progression spectrum.

Chapter 4: The reliability of jump kinematics and kinetics in children of different maturity status

Prelude

Monitoring seasonal changes or training adaptations of power is essential for an effective evidence-based model for power development. The vertical jump is a commonly used movement to assess leg power because of its simplicity and explosiveness. Due to the multi-directional nature of movement during most sports, monitoring horizontal power would also appear to be relevant. Analysis of vertical and horizontal jumping on a force plate not only allows monitoring of maximal power but also other kinetic and kinematic variables which may inform training prescription. However, it would seem impractical to utilise such protocols on youth populations if large within subject variability is associated with the variables of interest. Coordination pattern and movement control may change with growth and maturation, which could alter the reliability of jump kinematic and kinetic data. This information would be important to know when comparing training adaptations of youth athletes across different maturity group. Hence, the purpose of this study was to determine the reliability of eccentric and concentric kinematic and kinetic variables thought critical to jump performance during bilateral vertical and horizontal countermovement jumps across children of different maturity status.

Introduction

Power is regarded as a major physical determinant of becoming an elite team sport athlete (e.g. soccer, rugby, basketball, ice hockey) and therefore needs to be considered from an early stage of a player's identification and development. Leg power output can be measured during brief maximal intensity exercise such as cycling, sprinting or jumping. The assessment of "true" peak power requires measurements of instantaneous values of force and velocity [8, 9]. Cycling force-velocity power profiles of children and adolescents have been found to be reliable [15, 16] but the validity of such tests for field sport athletes is questionable [9]. Power assessment using jumping protocols is widely used in adult athletic populations and has been found valid [226, 227] and reliable [228-230]. Jump height as an indirect measure of leg power is largely used in pediatric populations [9] and has been found to be reliable [19, 231]. However, investigation of "true" power output in children derived from force platforms during vertical jumping is scarce [178, 232] and the reliability of associated measures remain unknown.

The combination of eccentric (ECC) followed by concentric (CON) muscle actions is a common type of muscular action required in athletic movement (e.g. sprinting, jumping) and is referred to as the stretch-shortening cycle (SSC). Recent literature [18] has demonstrated the relevance of monitoring multiple ECC and CON kinematic and kinetic variables (i.e. peak and mean force, peak and mean power, peak velocity, maximal displacement) in vertical countermovement jumps (i.e. SSC movement) following strength and power training. As suggested by other researchers [233-235], the ECC phase is crucial to the final outcome in bilateral vertical and horizontal countermovement jumps and can enhance jump performance from 10 to 15% compared to CON only jump performance (i.e. squat jump) [236, 237]. Therefore, to capture the underlying determinants of SSC performance (e.g. jump height) would seem important, however, the authors are unaware of any research that has taken such an approach in pediatric populations.

Team sport athletes are required to win challenges in the air (e.g. basketball, volleyball, soccer), justifying the need to assess vertical jumping ability and vertical power production. However, successful performance in many sports also involves movement characterized by substantial horizontal force and power production, such as sprinting [156]. The standing broad jump test (i.e. jump length) is widely used in athletic children [52] and has been found reliable [238] and validated as a general index of muscular fitness (3).

Similar to the research on vertical jumping, the reliability of a direct measure of horizontal power has only been investigated during a unilateral jump in adults [229] and to the knowledge of these authors has not been investigated in youth. Since the neuromuscular system is developing during growth and maturation [52], the reliability of measures established from adult studies do not necessarily translate to pediatric populations.

Previous studies have demonstrated that the coordination pattern involved in jumping is relatively stable from a very young age (i.e. 3 years old onwards) but control may be lacking [239, 240]. While coordination captures the movement's organization, control refers to the scalar definition of such features as displacement and velocity [241]. Adjustment of control variables tunes the performance to the context and the specific task demands and may also act as constraints, limiting the ability to conduct the task and setting the conditions for performance [240]. Previous research [19, 232, 242] has highlighted the reduction of jump height variability with age; however it did not investigate the change in movement control (e.g. ECC and CON kinematics and kinetics) across different maturity groups. Such a kinematic and kinetic investigation can provide insight into the control or stability of jump mechanics in youth. Considering the influence of maturation on the central nervous system development [52], the development of neural control in jumping [117] and potentially a disruption of motor control (i.e. "adolescent awkwardness") around peak height velocity (PHV) [135], it would appear worthwhile to investigate the reliability of ECC and CON kinematic and kinetic variables across different maturity groups. Such an approach would enable strength and conditioners as well as coaches working with athletes to determine whether jump assessments and the associated variables of interest can be used for monitoring children from various maturity status Hence, the purpose of this study was to determine the reliability of ECC and CON kinematic and kinetic variables thought critical to jump control and performance during a bilateral vertical (VCMJ) and horizontal (HCMJ) countermovement jump across children of different maturity status.

Methods

Experimental approach of the problem

Forty-two athletic children of different maturity status performed three trials of a VCMJ and HCMJ on three testing occasions to determine the inter-session variability of the eccentric and concentric kinematics and kinetics of the jumps. Further analysis was conducted to determine if the reliability of the dependant variables differed according to the maturity status of the athletes.

Subjects

Forty-two male and female subjects between 9 and 16 years of age from a youth sport development programme volunteered for this study. All children were nominated by their school as outstanding athletes to be involved in this programme and train a minimum of five hours per week in various sports. Subject characteristics are presented in Table 4.1. All testing procedures and risks were fully explained to the subjects and their parents/guardians. Both the subjects and their parents/guardians gave their written consent prior to the start of the study. The study was approved by the Human Research Ethics Committee of AUT University.

Testing procedures

Subjects attended three designated testing sessions at the same time of the day (morning) separated by seven days, in order to determine the inter-session reliability of two different jumps: the VCMJ and HCMJ. Prior to the first testing session, subjects were familiarised with the jumps as part of their training routine. During the first testing session, anthropometric measurements were taken before jump testing. The standing height (cm), sitting height (cm) and weight (kg) were measured and the body max index (BMI) calculated. Skinfold (mm) was measured at 4 sites: triceps, subscapular, supraspinale and medial calf, using a skinfold Slim Guide calliper (nearest 0.5 mm). The girth (cm) of arm flexed and tensed, and the calf were measured as well as the breadth (cm) of biepicondylar humerus and biepicondylar femur. All measurements were performed by a Level 1

Anthropometrist accredited by the International Society for the Advancement of Kinanthropometry (ISAK). Afterwards, the percentage body fat and somatotype were calculated according to the methods of Slaughter [243] and Carter [244], respectively. To estimate the maturity status of the athletes, a maturity index (i.e. timing of maturity) was calculated using the equation of Mirwald and colleagues [137]. This technique is a non-invasive and practical method of predicting years from PHV as a measure of maturity offset using anthropometric variables. Since an error of measurement of ± 0.5 years can occur (95% confidence interval) in this equation [137], percentage of predicted adult stature (PAS) was calculated using the method of Khamis and Roche [141] and used as an additional factor to identify the athletes' maturity status. Athletes were then split into three groups: Pre-PHV velocity (-3 years to -1 years from PHV and 79-88% PAS; boys = 14, girls = 5), At-PHV (-1 to +1 years from PHV and 89-95% PAS; boys = 5, girls = 7) and Post-PHV (+1 to +3 years from PHV and 96-99% PAS; boys = 3, girls = 8).

Table 4.1. Anthropometric characteristics of the groups based on peak height velocity (PHV)

Variables	Pre PHV (F = 5; M = 14)	At PHV (F = 7; M = 5)	Post PHV (F = 8; M = 3)
Age (y)	10.9 ± 1.2	12.6 ± 1.13	14.5 ± 1.3
Height (cm)	147 ± 7.5	157 ± 7.3	167 ± 9.4
Mass (kg)	40.0 ± 5.5	48.9 ± 5.9	61.4 ± 11.8
PHV offset (y)	-2.1 ± 0.7	-0.1 ± 0.4	2.2 ± 0.7
Relative height (%)[a]	83.5 ± 3.0	92.2 ± 1.7	98.2 ± 1.2
Body mass index (kg.m^{-2})	18.3 ± 1.9	19.7 ± 1.6	21.6 ± 2.6
Body fat (% bodymass)	16.8 ± 5.4	16.3 ± 3.3	22.4 ± 4.4
Sum 4 skinfold (mm)	33.5 ± 12.6	33.1 ± 5.5	49.6 ± 11.3
Endomorph	2.6 ± 1.2	2.5 ± 0.6	3.6 ± 1.0
Mesomorph	4.3 ± 1.0	4.3 ± 0.9	4.1 ± 0.8
Ectomorph	3.2 ± 1.1	3.1 ± 0.9	2.4 ± 0.9

After the anthropometric measurements, subjects undertook a 10 minute standardized warm-up consisting of five minutes of jogging followed by a series of dynamic movements (e.g. lunges and skipping). Subjects performed three trials of the VCMJ and HCMJ with approximately 30 s recovery between trials within jump type and 120 s between jump types. During every jump, subjects were asked to keep their arms akimbo to eliminate arm swing. This instruction was given to isolate the lower limb musculature, eliminating the influence of the upper limb at the hip joint [245], and reducing

the importance of skill and coordination. No specific instructions were given to the subjects in regards to the depth or speed of the countermovement but subjects were instructed to jump as high or far as possible. The VCMJ consisted of flexion (ECC phase) and then extension (CON phase) until takeoff and landing on two feet. For the HCMJ, the same starting protocol as the vertical countermovement jump was used but the subject jumped as far as possible and stick their landing on two feet [238].

Data analysis

Vertical and anterior-posterior (i.e. horizontal) ground reaction force (GRF) data were collected with a portable plate (AMTI, ACP, Watertown, MA) using a sampling rate of 400 Hz. A custom designed Labview (National Instruments, Austin, TX) force plate analysis program was used to calculate the variables of interest. Initiation of the jump movement was defined as the point where the force-time curve dropped below a threshold of 2.5% bodyweight as shown in Figure 4.1 [246]. The end of the jump was calculated from when the force dropped to zero, the difference between the initiation threshold and zero force is termed the ground contact time. Vertical GRF was divided by the mass of the subject at each time point in order to determine acceleration of the centre of mass. Acceleration due to gravity was subtracted from the calculated acceleration data to ensure that only the acceleration produced by the subject was obtained. To calculate velocity and displacement, the acceleration-time curve obtained from the force-time data were numerically integrated using the Simpson method [247]. The derived velocity data were multiplied by the original force values in order to calculate power. The area under the force-time curve represents impulse, and effects due to gravitational acceleration were removed from total impulse to quantify net impulse. Take-off velocity was then calculated from the impulse-momentum relationship and an equation of constant acceleration (take-off velocity^2/2*gravity) was used to estimate jump height.
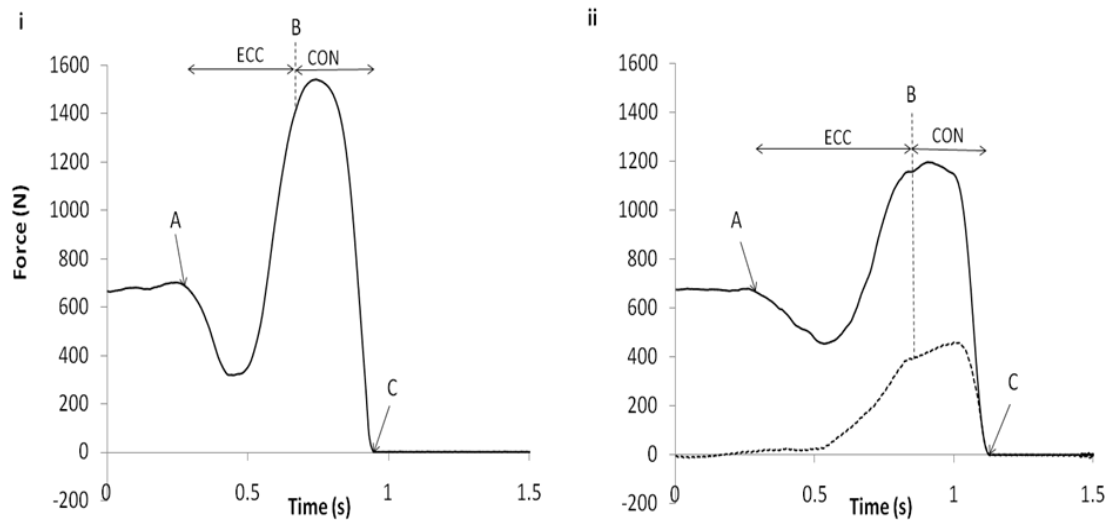
Figure 4.1. Force-time curve of the vertical (i), horizontal (ii), countermovement jump trial of a 69 kg subject. Vertical ground reaction force (solid line); anterior-posterior ground reaction force (dash line); A: start of the countermovement at 2.5% bodyweight; B: force at bottom position (zero velocity); C: takeoff; Ecc: eccentric; Con: concentric

The movement time was divided into an ECC phase (i.e. lengthening phase) and a CON phase (i.e. shortening phase) as shown in Figure 4.1. For the vertical GRF, the start of the CON phase was determined when velocity of the centre of mass became positive, which corresponds to the minimum displacement of the centre of mass [248]. In terms of kinematic variables, the ECC and CON ground contact time, the maximal ECC and CON velocity, and the ECC displacement of the centre of mass (i.e. bottom position of countermovement) were recorded. The kinetic variables of interest were peak and mean force and peak and mean power for both the ECC and CON phase.

Horizontal variables were also split into ECC and CON phases which were defined from the vertical motion of the centre of mass obtained from the vertical GRF analysis described above. Horizontal acceleration of the centre of mass was calculated from the force-time signal. It should be noted that the effect of gravity was not considered as an external force as it affects the vertical component only [249]. The acceleration-time curve was then integrated using the same method as for the vertical GRF analysis to obtain velocity, and power output was derived when velocity was multiplied by the force. Peak force, mean force, peak power and mean power were recorded for the CON phase. From the vertical and horizontal take-off velocity, resultant velocity was calculated using the pythagorean relationship [250] and angle at take-off was calculated using trigonometric

functions [250]. Jump length was determined using a projectile motion formula created by the original software manufacturer (AccuPower, Version 1.5, Athletic Republic, Fargo, ND). Data analysis of similar nature has been used elsewhere [228, 229, 246].

Statistical analysis

Following data collection, means and standard deviations were calculated for all results. The three trials for all jump variables were averaged for an individual subject mean, and subject means for each variable were averaged in each maturity group to provide a group mean for each testing occasion. The inter-session reliability of the variables was calculated using three different statistical methods using pairwise comparisons on the log-transformed data, with log-transformation reducing the effects of any non-uniformity of error [251]. Pairwise comparisons were conducted to observe the reliability from session to session rather than a mean of the reliability measures across the three testing sessions. The standard error of measurement, expressed as a coefficient of variation (CV), was reported to determine the absolute reliability or within subject variation of the different variables [251]. Percent change in the mean (CM) was reported to indicate the extent to which the average performance got better or worse over testing occasion due to systematic effects (e.g. learning effect) and random effect (e.g. noise) [251]. Relative reliability was quantified via an intraclass correlation coefficient (ICC), which refers to the consistency of the rank or position of an athlete in relation to others. The level of acceptance for reliability was a CV $\leq$ 15% [252] and ICC $\geq$ 0.70 [253]. To determine whether the reliability between groups was different, we compared the CV of two groups (i.e. Post- PHV vs. At-PHV and At-PHV vs. Pre-PHV) by calculating the confidence intervals for the ratio of the CV of sessions 2-3, using the fact that the sampling distribution of the ratio of the sample to population variances in the two groups is an *F*-distribution. We regarded a CV that differed by a factor of 1.15 or more as being substantially different, because the effect of such a difference on sample size in a controlled trial of competitive performance is a factor of 1.15 [251, 254, 255], or a change in sample size of 32%. The chance of "beneficial/better" or "detrimental/poorer" reliability were assessed qualitatively as follows: <1% was described as "most unlikely", 1% to 5% as "very unlikely", 5% to 25% as "unlikely", 25% to 75% as "possibly", 75% to 95% as "likely", 95% to 99% as "very likely", >99% as "most likely". If the chance of having "beneficial/better" or "detrimental/poorer" reliability between

groups were both >5%, the true difference was assessed as "unclear" [186]. The same procedure was used to compare the reliability of the dependant variables from session 1-2 to 2-3. Ninety percent confidence intervals (90% CI) were reported for all statistical analyses. Descriptive statistics and reliability measures were computed through Microsoft Excel® 2007 [256, 257].

Results

The variables found reliable for both jumps across the three maturity groups and testing occasions can be observed in Tables 4.2 to 4.4. ECC and CON peak and mean vertical force as well as CON vertical impulse were found highly reliable in the VCMJ and HCMJ across the three groups (CM = -3.6% to 5.5%; CV = 0.7% to 9.3%; ICC = 0.83 to 1.00). However, ECC vertical impulse reliability was just acceptable (CM = -5.8% to 11.6%; CV = 4.7% to 15.2%; ICC = 0.76 to 0.96). Horizontal CON peak and mean force as well as CON horizontal impulse were found to be as reliable as the vertical force components during the HCMJ (CM = 0.3% - 8.8%; CV = 5.1% - 9.9%; ICC = 0.85 – 0.97). Considering that the reliability of these variables was not affected by mathematical integration and rarely used as direct measures of performance (e.g. power, jump height) or movement control (e.g. displacement), they were not presented in the tables or included in between groups analysis to keep the information concise.

All other CON variables of the VCMJ investigated as well as jump height were more reliable than the ECC variables and were classified as highly reliable (CM = -2.4% to 4.6%; CV = 2.1% to 8.9%; ICC = 0.82 to 0.98) apart from contact time which was slightly less reliable but still acceptable (CM = 0.5% to 5%, CV = 6.0% to 9.7%; ICC = 0.74 to 0.82). Mean ECC power was the only ECC variable found to have acceptable reliability across the three groups (CM = -0.7% to 10.1%; CV = 5.2% to 14.3%; ICC = 0.74 to 0.95). All other ECC variables (i.e. peak power, displacement, peak velocity and contact time) were found unreliable at least in one group (CM = -0.3% to 12.4%; CV = 5.2% to 26.2%; ICC = 0.24 to 0.92) but no substantial difference in reliability across the groups were found. Generally, the CV and ICC of these measures improved from sessions 1-2 to sessions 2-3 (Session 2-3: CM = -5.6% to 17.2%; CV = 5.7 to 14.3%; ICC = 0.70 to 0.90). However, the magnitude based inference statistics conducted on the CV 1-2 to 2-3 showed that only the reliability of ECC displacement was "likely" to improve from session to

session in Post-PHV and that ECC peak power and peak velocity were "very likely" and contact time was "likely" to improve in the At-PHV group from session to session.

Table 4.2. Reliability statistics (90% confidence limits) for the kinematics, power and jump performance of the VCMJ and HCMJ in children more than one year post peak height velocity

Variables	Means ± SD	Change in the mean (%)		Coefficient of variation (%)		Intraclass Correlation	
Eccentrics VGRF	Session 1	Session 1-2	Session 2-3	Session 1-2	Session 2-3	Session 1-2	Session 2-3
VCMJ mean power (W)	373 ± 84	2.1	10.1	9.1	7.6	0.90	0.93
		(-4.5, 9.2)	(4.0, 17)	(6.7, 15)	(5.6, 12)	(0.72, 0.96)	(0.80, 0.97)
HCMJ mean power (W)	324 ± 98	7.9	3.0	11	7.9	0.91	0.93
		(-0.1, 17)	(-3.2, 10)	(7.6, 17)	(5.7, 13)	(0.75, 0.97)	(0.80, 0.98)
Concentrics VGRF							
VCMJ peak power (W)	2450 ± 530	1.1	3.6	4.2	4.4	0.97	0.97
		(-2.0, 4.4)	(0.3, 7.1)	(3.1, 6.8)	(3.2, 7.0)	(0.92, 0.99)	(0.92, 0.99)
HCMJ peak power (W)	1490 ± 440	-0.6	-5.4	12	9.0	0.84	0.90
		(-8.7, 8.2)	(-12, 1.5)	(8.4, 19)	(6.5, 15)	(0.59, 0.94)	(0.71, 0.96)
VCMJ mean power (W)	1370 ± 260	-2.0	2.6	5.8	4.8	0.94	0.96
		(-6.2, 2.3)	(-1.1, 6.4)	(4.2, 9.3)	(3.5, 7.7)	(0.82, 0.98)	(0.88, 0.99)
HCMJ mean power (W)	862 ± 204	-2.0	-3.2	10	6.3	0.83	0.94
		(-9.0, 5.6)	(-7.9, 1.8)	(7.4, 17)	(4.6, 11)	(0.56, 0.94)	(0.83, 0.98)
VCMJ displacement (cm)	39.8 ± 5.8	3.2	4.6	6.3	6.1	0.86	0.85
		(-1.5, 8.2)	(-0.1, 9.5)	(4.6, 10)	(4.5, 10)	(0.62, 0.95)	(0.61, 0.95)
VCMJ peak velocity (m.s^{-1})	2.35 ± 0.18	0.2	2.3	2.1	2.2	0.96	0.95
		(-1.3, 1.8)	(0.6, 4.1)	(1.5, 3.3)	(1.6, 3.6)	(0.88, 0.99)	(0.86, 0.98)
VCMJ contact time (ms)	293 ± 34	5.0	2.2	6.6	6.0	0.75	0.78
		(-0.1, 10)	(-2.4, 6.9)	(4.9, 11)	(4.4, 10)	(0.39, 0.91)	(0.47, 0.92)
Concentrics HGRF							
HCMJ peak power (W)	817 ± 251	8.8	4.7	12	15	0.89	0.84
		(-1.1, 20)	(-7.7, 19)	(8.9, 21)	(11, 28)	(0.69, 0.96)	(0.53, 0.95)
Others							
VCMJ jump height (cm)	26.1 ± 4.6	0.8	4.8	4.5	5.1	0.96	0.95
		(-2.6, 4.3)	(0.9, 8.9)	(3.3, 7.3)	(3.7, 8.2)	(0.88, 0.99)	(0.85, 0.98)
HCMJ resultant TO velocity (m.s^{-1})	2.64 ± 0.25	3.7	1.2	2.7	3.6	0.95	0.91
		(1.6, 5.9)	(-1.7, 4.2)	(2.0, 4.4)	(2.6, 6.0)	(0.85, 0.98)	(0.74, 0.97)
HCMJ jump length (cm)	147 ± 19	6.2	3.2	6.0	3.8	0.87	0.96
		(1.3, 11)	(-0.1, 6.6)	(4.3, 10)	(2.7, 6.6)	(0.63, 0.96)	(0.87, 0.99)

VGRF = vertical ground reaction force; HGRF = horizontal ground reaction force; VCMJ = vertical countermovement jump; HCMJ = horizontal countermovement jump; TO = take off

Table 4.3. Reliability statistics (90% confidence limits) for the kinematics, power and jump performance of the VCMJ and HCMJ in children one year before to after peak height velocity

Variables	Means ± SD	Change in the mean (%)		Coefficient of variation (%)		Intraclass Correlation	
Eccentrics VGRF	Session 1	Session 1-2	Session 2-3	Session 1-2	Session 2-3	Session 1-2	Session 2-3
VCMJ mean power (W)	280 ± 81	5.6 (-4.2, 17)	7.8 (2.4, 14)	14.3 (10.5, 23)	7.3 (5.4, 12)	0.74 (0.42, 0.90)	0.90 (0.75, 0.96)
HCMJ mean power (W)	266 ± 73	4.2 (-2.0, 11)	5.8 (-1.4, 13)	8.3 (6.0, 14)	9.5 (6.9, 16)	0.92 (0.77, 0.97)	0.91 (0.75, 0.97)
Concentrics VGRF							
VCMJ peak power (W)	2080 ± 580	0.9 (-2.9, 4.8)	3.1 (0.4, 5.9)	5.4 (4.0, 8.5)	3.8 (2.8, 5.9)	0.96 (0.90, 0.99)	0.98 (0.95, 0.99)
HCMJ peak power (W)	1200 ± 410	-7.6 (-16, -1.3)	1.2 (-4.4, 7.2)	13.4 (9.9, 22)	7.7 (5.6, 13)	0.86 (0.65, 0.95)	0.94 (0.83, 0.98)
VCMJ mean power (W)	1170 ± 370	3.3 (-3.0, 10)	2.7 (0.2, 5.4)	8.9 (6.6, 14)	3.5 (2.6, 5.5)	0.92 (0.79, 0.97)	0.98 (0.96, 0.99)
HCMJ mean power (W)	710 ± 240	-5.1 (-14, 4.1)	3.5 (-2.2, 10)	13.5 (9.9, 22)	7.7 (5.6, 13)	0.84 (0.60, 0.94)	0.91 (0.75, 0.97)
VCMJ displacement (cm)	36.3 ± 6.7	3.8 (-1.9, 10)	1.7 (-3.5, 7.0)	8.0 (5.9, 13)	7.3 (5.4, 12)	0.83 (0.59, 0.94)	0.82 (0.57, 0.93)
VCMJ peak velocity (m.s-1)	2.35 ± 0.26	1.1 (-1.7, 4.0)	1.6 (-0.2, 3.5)	3.9 (2.9, 6.1)	2.5 (1.9, 4.0)	0.87 (0.67, 0.95)	0.93 (0.82, 0.98)
VCMJ contact time (ms)	273 ± 51	1.5 (-5.1, 8.6)	0.5 (-4.5, 5.6)	9.7 (7.1, 15)	7.1 (5.3, 11)	0.74 (0.42, 0.90)	0.82 (0.57, 0.93)
Concentrics HGRF							
HCMJ peak power (W)	734 ± 245	7.1 (-2.9, 18)	7.4 (-1.2, 17)	14.3 (10.5, 23)	11.3 (8.3, 19)	0.84 (0.61, 0.94)	0.90 (0.72, 0.96)
Others							
VCMJ jump height (cm)	26.4 ± 6.3	2.8 (-3.3, 9.2)	3.6 (-0.3, 7.7)	8.7 (6.4, 14)	5.4 (4.0, 8.4)	0.86 (0.66, 0.95)	0.94 (0.83, 0.98)
HCMJ resultant TO velocity (m.s-1)	2.66 ± 0.25	-0.5 (-3.4, 2.5)	3.5 (1.2, 5.8)	4.1 (3.1, 6.5)	2.9 (2.1, 4.6)	0.86 (0.65, 0.95)	0.92 (0.78, 0.97)
HCMJ jump length (cm)	149 ± 20	-3.7 (-7.2, 0.1)	2.3 (-1.5, 6.3)	5.0 (3.7, 8.1)	4.8 (3.5, 8.0)	0.91 (0.75, 0.97)	0.91 (0.74, 0.97)

VGRF = vertical ground reaction force; HGRF = horizontal ground reaction force; VCMJ = vertical countermovement jump; HCMJ = horizontal countermovement jump; TO = take off

Table 4.4. Reliability statistics (90% confidence limits) for the kinematics, power and jump performance of the VCMJ and HCMJ in children more than one year prior to peak height velocity

Variables	Means ± SD	Change in the mean (%)		Coefficient of variation (%)		Intraclass Correlation	
Eccentrics VGRF	Session 1	Session 1-2	Session 2-3	Session 1-2	Session 2-3	Session 1-2	Session 2-3
VCMJ mean power (W)	209 ± 44	2.9	-0.7	5.2	7.4	0.95	0.93
		(0.1, 5.9)	(-4.6, 3.4)	(4.1, 7.2)	(5.8, 10)	(0.90, 0.98)	(0.85, 0.97)
HCMJ mean power (W)	186 ± 59	3.4	2.9	16	4.6	0.79	0.97
		(-4.7, 12)	(0.3, 5.7)	(12, 22)	(3.6, 6.6)	(0.59, 0.90)	(0.94, 0.99)
Concentrics VGRF							
VCMJ peak power (W)	1480 ± 280	5.1	0.7	3.7	3.6	0.97	0.97
		(3.0, 7.3)	(-1.3, 2.8)	(2.9, 5.1)	(2.9, 5.1)	(0.94, 0.99)	(0.94, 0.99)
HCMJ peak power (W)	922 ± 192	-3.4	-4.4	7.2	8.7	0.91	0.88
		(-7.1, 0.5)	(-9.0, 0.3)	(5.7, 10)	(6.8, 12)	(0.80, 0.96)	(0.75, 0.94)
VCMJ mean power (W)	825 ± 131	5.2	-1.1	5.9	5.8	0.90	0.92
		(1.9, 8.6)	(-4.2, 2.1)	(4.6, 8.2)	(4.6, 8.2)	(0.80, 0.95)	(0.83, 0.96)
HCMJ mean power (W)	534 ± 91	-2.9	-2.7	6.9	7.6	0.88	0.87
		(-6.5, 0.8)	(-6.8, 1.5)	(5.4, 9.7)	(5.9, 11)	(0.75, 0.94)	(0.72, 0.94)
VCMJ displacement (cm)	33.4 ± 5.5	-1.3	1.7	4.9	6.2	0.92	0.87
		(-3.9, 1.3)	(-1.6, 5.2)	(3.8, 6.8)	(4.8, 8.6)	(0.82, 0.96)	(0.73, 0.94)
VCMJ peak velocity (m.s^{-1})	2.17 ± 0.19	1.5	0.1	3.1	2.6	0.90	0.93
		(-0.2, 3.3)	(-1.3, 1.6)	(2.4, 4.3)	(2.0, 3.6)	(0.80, 0.96)	(0.85, 0.97)
VCMJ contact time (ms)	268 ± 39	-2.4	2.6	7.2	8.4	0.79	0.79
		(-6.2, 1.5)	(-1.9, 7.4)	(5.7, 10)	(6.5, 12)	(0.59, 0.90)	(0.58, 0.90)
Concentrics HGRF							
HCMJ peak power (W)	451 ± 127	12	12	15.0	10.6	0.81	0.91
		(3.6, 21)	(5.9, 19)	(12, 21)	(8.2, 15)	(0.61, 0.91)	(0.80, 0.96)
Others							
VCMJ jump height (cm)	21.9 ± 4.3	4.2	0.3	7.1	5.8	0.90	0.93
		(0.3, 8.3)	(-2.8, 3.5)	(5.6-9.9)	(4.5, 8.1)	(0.80, 0.96)	(0.86, 0.97)
HCMJ resultant TO velocity (m.s^{-1})	2.43 ± 0.22	1.1	3.2	4.5	2.0	0.78	0.95
		(-1.4, 3.6)	(2.0, 4.4)	(3.6-6.3)	(1.6, 2.8)	(0.57, 0.89)	(0.90, 0.98)
HCMJ jump length (cm)	124 ± 23	0.4	2.4	9.4	6.1	0.63	0.83
		(-4.6, 5.6)	(-1.1, 6.0)	(7.4-13)	(4.8, 8.7)	(0.34, 0.82)	(0.65, 0.92)

VGRF = vertical ground reaction force; HGRF = horizontal ground reaction force; VCMJ = vertical countermovement jump; HCMJ = horizontal countermovement jump; TO = take off

The ECC variables (i.e. peak and mean power, displacement, peak velocity and contact time) derived from the vertical GRFs of the HCMJ followed the same pattern as the ECC variables of the VCMJ. High initial variability was observed between sessions 1 and 2 (CM = 0.6 to 11.1%; CV = 7.5% to 20.9%; ICC = 0.19 to 0.92) but reliability improved between sessions 2 and 3 (CM = -1.6% to 13.3%; CV = 5.3% to 12.7%; ICC = 0.74 to 0.97). The magnitude based inference statistics conducted on the CV 1-2 to 2-3 demonstrated that the reliability of ECC peak vertical power was "very likely" to improve in both Post-PHV and Pre-PHV groups, ECC contact time reliability was "likely" to improve in At-PHV group and that both ECC displacement and ECC peak velocity reliability were "likely" to improve in Pre-PHV group. Again, mean ECC power was the most reliable ECC measure, especially in session 2-3 (CM = 2.9% - 5.8%; CV = 4.6% - 9.5%; ICC = 0.91 – 0.97). The CON variables derived from vertical GRFs during the HCMJ were not as reliable as during the VCMJ. Mean and peak CON power were the only variables considered to have acceptable reliability across the groups and sessions (CM = -7.6% to 3.5%; CV = 6.3% to 11.6%; ICC = 0.83 to 0.94). CON displacement and contact time were unreliable (CM = -10.0% to 3.8%; CV = 6.7 to 14.7; ICC = 0.48 to 0.87). Takeoff angle decreased from session to session, which was considered unreliable (CM = -8.8% to -1.8%; CV = 9.3% to 12.6%; ICC = 0.31 to 0.76). Regarding the horizontal power production during the HCMJ, peak power was deemed acceptable (CM = 4.1% to 12.1%; CV = 10.6% to 15.4%; ICC = 0.84 to 0.91) and mean horizontal power was close to being acceptable (CM = 5.0% to 17%; CV = 11.7% to 16.6%; ICC = 0.78 to 0.89). Finally, both resultant takeoff velocity and jump length were found highly reliable across the three groups (CM = -3.7% to 6.2%; CV = 2.7% to 9.4%; ICC = 0.83 to 0.96), apart from resultant takeoff velocity and jump length of the Pre-PHV group in the session 1-2 comparison (ICC = 0.78 and ICC = 0.63, respectively).

Of the 16 variables investigated and 64 comparisons made between groups in terms of reliability, only six comparisons found that the reliability could be "likely" to "very likely" different between groups. During the VCMJ, the CON mean power of the Pre-PHV was found to be "likely" more variable than the AT-PHV (CV ratio = 1.66 – CI = 1.03 to 2.66), but both values were accepted as reliable (CV sessions 2-3 = 3.5% and 5.8%). During the HCMJ, the variability in ECC variables amongst the groups increased as maturity decreased. Compared to the Post-PHV group, At-PHV group was "likely" (CV ratio = 0.46 – CI = 0.25-0.87) and "very likely" (CV ratio = 0.58 – CI = 0.33-1.04) to be

more unreliable for the ECC peak power and ECC peak velocity, respectively, and Pre-PHV was "likely" (CV ratio = 1.55 – CI = 0.94-2.56) to have more variability in ECC contact time and "very likely" (CV ratio = 0.48 – CI = 0.29-0.80) to be more unreliable in ECC mean power than At-PHV. All ECC variables were considered unreliable in all groups apart from ECC mean power. Resultant takeoff velocity was also found to be "likely" more variable in the Pre-PHV than At-PHV (CV ratio = 0.69 – CI = 0.43-1.12), but the reliability of this variable was deemed acceptable in both groups

Discussion

The purpose of this study was to quantify the reliability of ECC and CON kinetic and kinematic variables during a VCMJ and HCMJ performed by three maturity groups. Previous studies [230, 258-260] have demonstrated the reliability of CON peak and mean force, peak and mean power and peak velocity as well as jump height during a VCMJ in adult populations (CV = 2.1 – 11.1%; ICC = 0.80 – 0.97). However, the current study was the first study to determine reliability of these measures across three different maturity groups of children (Table 4.2 to 4.4). The underlying rationale for the study was to determine if reliability was similar across maturity status and also similar to adult data published in the literature. If similar it would seem that the testing procedures used in this study could be applied across many populations irrespective of age/maturation.   If dissimilar, consideration would need to be given to modifying testing procedures such as better familiarization.

Previous researchers [233-235] have suggested that the ECC phase of each jump was particular to the jump type performed, influenced the subsequent CON phase and therefore needed to be addressed individually. ECC peak power, velocity and displacement have been used in previous literature to monitor adaptation to training [18] in VCMJ, determine the stability of jump mechanics control [228, 261], and detect the importance of ECC variables in jump performance [228]. ECC minimal force during a VCMJ (i.e. unloading phase) has also been used but found relatively unreliable in adults (CV = 13.6-14.5%) [258]. In this sense, the current study determined that only ECC mean power, peak and mean force and impulse during VCMJ can be used in children of different maturity status due to the variability associated with the rest of the ECC variables. As for the VCMJ, only vertical ECC mean power, vertical ECC peak and mean force and ECC impulse during

93

HCMJ were considered reliable measures to monitor training when assessing ECC muscular capability. The study of Jensen et al. [261] provided evidence that of the flexion and extension phases of the jump, the flexion was most variable. The joint displacement and velocity patterns associated with lower extremity flexion appear less constrained, and adaptations to the task are made during this phase (i.e. control). In contrast, the kinematics of the propulsive phase were characterised by reduced variability due to the smaller degrees of freedom [261]. The fact that the reliability of the ECC variables of HCMJ improved from sessions 1-2 to sessions 2-3 and marginally from Pre-PHV to Post-PHV groups suggest that the complexity of the HCMJ required greater motor control or is not utilised as much as the VCMJ, hence better familiarisation may be needed. This hypothesis is supported by the increased variability of vertical CON measures for the HCMJ, where displacement and contact time were unstable from session to session, which in turn affected the reliability of takeoff angle. While biomechanical data varied, jump length did not vary substantially, suggesting that children can alter their strategy to maintain jump performance in the HCMJ. Previous studies [233-235] have shown differences in joint kinematics, kinetics and electromyography activity between bilateral vertical and horizontal countermovement jumps, which is likely to account for the difference in force distribution (i.e. vertical vs. horizontal) [229] and kinematics (i.e. displacement, velocity) [228] of the centre of mass between the two activities. These differences in movement patterns between the two jumps may explain the greater variability in the vertical kinetics and kinematics of the HCMJ compared to the VCMJ found in the current study and prior investigations on the topic [228, 229]. Considering the lack of reliability of other ECC variables, vertical ECC mean power, peak and mean force and impulse would be the measures of choice to determine ECC training adaptation during both VCMJ and HCMJ [18, 229].

The reliability of vertical peak and mean CON power during both the VCMJ and HCMJ demonstrated that these measures can be used for monitoring of power across maturity groups. The reliability of horizontal CON peak and mean power were also investigated to provide a measure relevant to the multi-planar nature of force production during sports movement (e.g. sprinting) and has been previously described as a good predictor of single leg HCMJ ability in adults ($r^2 = 42.6\%$) [229]. Both measures were found to be of similar reliability to previous findings during a single leg HCMJ (ICC = 0.77 − 0.84) [229], but must be used with caution considering the learning effect from session to session, especially in the Pre-PHV group (CM = 11.7% - 17%). Previous research has

suggested that jump height variability in the VCMJ and squat jump is greatest in younger subjects and recedes with growth and maturation [19, 232, 242]. This notion is reinforced in other studies in both adults [262] and children [19], indicating the existence of jump-specific motor control adaptations due to training (i.e. jumping expertise). Based on the theory of skill acquisition during growth and maturation, the current study showed that some maturity-related differences in motor control strategies may exist during the CMJ's, especially in the ECC phase of the HCMJ. However, less than 10% of the reliability comparisons were found to be "likely" to "very likely" different between groups. Hence, for most comparisons, the reliability of the variables of interest were found comparable between maturity groups and, for the most part, it would seem that similar jump protocols can be used irrespective of age/maturity. This relative discrepancy with previous literature can be explained by the fact that our sample was very active and therefore stabilization of jump mechanics may have already occurred considering the simplicity of the jumps. It is possible that the results may have differed in more complex jump task (i.e. rebound or drop jumps) [117]. Also, group comparison were based on CV's and CI's. A larger sample could have resulted in the same CV's but much narrower CI's, making the possibility of finding differences between groups more likely. The results of the current study must be interpreted with these limitations in mind.

In practical settings, jump height or jump length is usually used as an indirect measure of leg power [263, 264]. Compared to previous studies in children, jump height was found to be more reliable across all age groups than recently reported in 13-14 years old boys (CV = 12.9% − 14.5%; ICC = 0.83) [231]. The difference in reliability may be attributed to the method of calculating jump height. The present study calculated jump height using the take-off velocity derived from the impulse-momentum relationship, which has been used as the reference method in the literature [265]. Despite the fact that using flight time to calculate jump height [231] has been validated [265], an important assumption is made that the body positions at the instant of takeoff and landing are the same (i.e. full extension at the hips, knees and ankles). Variation in landing technique (e.g. flexed knees, hips and ankles), which is likely to occur in children, can decrease the reliability of jump height [266]. Again, the differences of our findings to previous literature could also be due to the more athletic nature of the current sample, leading to greater motor control of the jump tasks.

Jump length, as the performance measure of a HCMJ, is dependent on the takeoff angle and resultant velocity as far as the propulsive phase of the jump is concerned. As previously discussed, takeoff angle is associated with relatively high variability and should not be used. However, resultant velocity was found highly reliable across all groups, demonstrating that total impulse (i.e. horizontal and vertical), which yields resultant velocity, remained constant from session to session. Jump length measured from the propulsive phase was found highly reliable except for the Pre-PHV group which demonstrated some inter-individual variability (sessions 2-3 ICC = 0.63). Previous data on the topic has shown slightly better reliability for jump length during a bilateral (CV = 2.9%; ICC = 0.95) [238] or unilateral (CV = $1.9 - 4.8$%; ICC = $0.87 - 0.95$) [229, 267] HCMJ. However, adults were used as subjects in these studies. As previously discussed, maturity could play a role in motor control during horizontal jumping. Also, the method used to measure jump length differed between the current study and previous research. While a tape measure was used in prior investigations to record jump length, the current study used a projectile motion formula created by the original software manufacturer (AccuPower, Version 1.5, Athletic Republic, Fargo, ND). The variability of the measurement could change depending on the method of measurement and equipment-specific typical error needs to be taken into account when a change in performance is to be determined [251]. The propulsive phase was calculated using the impulse-momentum relationship which is likely to increase the typical error due to mathematical integration. However, it can be argued that the value measured, reflected the propulsive phase better than a tape measure, which is affected by airborne and landing technique. The current formula made a constant assumption on landing angle which reduces the relationship with the true measure of jump length (i.e. tape measure). Data from our laboratory showed a shared variance of only 43% between the two measures (i.e. projectile motion formula and tape measure) on a sample of 112 children (unpublished data). Due the ease of measurement and reduced typical error, the tape measure should be used to assess jump length, unless the propulsive phase itself is of interest. In any case, particular caution must be taken when selecting the method to measure both jump length and jump height.

Finally, a point of contention is the gender issue of the current sample. On one hand, there is less males in the Post-PHV group (n = 3), and this population could be expected to significantly increase their muscle mass in a short period of time, which may increase variability during this period. Instead this group were mostly females (n = 8), who

were most likely to add more fat and not muscle as a result of maturation [52, 111]. Furthermore, as the Post-PHV group were mostly females, this reduced the chronological age since females mature earlier than males [52]. This may reduce the reliability of this group due to less experience in jump control. Having said that, previous studies [136] have demonstrated that performance spurts in jumping (i.e. cm/year) occur at similar times in relation to PHV in both genders (i.e. at PHV to the year following PHV). Since the timing of jumping development is not gender specific when aligned with PHV, it can be hypothesised that the associated motor control of jumping tasks is not gender specific either. Therefore, jump variability is unlikely to be influenced by gender differences, unless the gender specific magnitude in performance spurt plays a role (e.g. 21-22 cm/year and 12 cm/year in the standing long jump for boys and girls, respectively) [136]. This limitation must be kept in mind when interpreting the data of the current study.

Practical applications

It was found that over 90% of the variables investigated in this study can be interpreted in a similar manner in terms of reliability regardless of maturity (-3 years to +1 year from PHV). ECC kinematic variables of both the VCMJ and HCMJ were not reliable across all maturation groups. It seems that larger freedom of movement occurs during the ECC phase of CMJs, requiring greater motor control. Therefore, during the familiarisation of CMJ's, emphasis should be placed on the ECC phase to reduce variability. In addition, training programmes in youth should concentrate on optimal ECC mechanics to improve CON measures considering the potential role of this phase to enhance CON power output and jump performance. Vertical ECC mean power, or power absorption, appeared to be a reliable measure in both CMJs and across all groups. Therefore, in a practical, applied setting where information regarding adaptations to training is required immediately, mean ECC power can be used as a simple indicator of whether the training intervention elicited alterations to SSC function. In addition, CON mean and peak power can be used across all maturity groups to monitor the efficacy of training interventions. Since different training regimes may elicit various adaptations, the ability to monitor both ECC and CON variables during CMJs is appealing as it enables a differentiation of changes within SSC function. Finally, both jump height and jump length calculated from total impulse can be used confidently as performance measures across maturity groups. As the HCMJ jump

97

performance requires multi-planar force production, greater familiarisation to the movement compared to the VCMJ should be allowed, especially in Pre-PHV children. Future research should quantify the relationship of the reliable variables with performance measures (e.g. jump height/length, speed, agility) to address the validity of these measures in pediatric population. Furthermore, the magnitude of change associated with training across different maturity groups should be conducted to determine the ability of the current variables to monitor training adaptations during growth and maturation.

Chapter 5: Isointerial assessment of the force-velocity-power relationship and maximal strength in youth

Prelude

Most kinematic and kinetic variables from unloaded vertical and horizontal countermovement jumps can confidently be used for monitoring across different maturity groups. Adding load to the same movement could be used to determine the force-velocity-power profile of the youth athlete. Such profiling may provide valuable insight into neuromuscular capabilities during growth and maturation and may be used to monitor specific training adaptations. But, using loaded jumps may not be advisable for general pediatric populations due to poor technique of squatting or landing and potentially excessive loading of the growing spine. The implementation of a ballistic loading protocol on a device where the back is rigidly supported would reduce these risks and capture the force-velocity-power variables of interest. The use of an inerital dynamometer attached to the weight stack of a supine squat machine is one device that may provide such information in a safe and effective manner. For example, establishing the load-velocity relationship would enable estimation of an individual one-repetition maximum (1RM) without necessarily lifting maximal loads. Considering that an isoinertial ballistic loading protocol on a supine leg press has never been implemented in youth, the aim of this study was to quantify the reliability of the kinematics and kinetics of this movement across different loads. Furthermore, the variability of regression lines to predict maximum power and the associated optimal load and velocity, predicted 1RM, as well as maximal force and velocity were also of research interest.

Introduction

Maximal power output is the product of force and velocity and is defined and limited by the force-velocity relationship [268, 269]. On this basis, maximal power output may improve by increasing the ability to develop high levels of force at a given velocity (i.e. force capability or strength) and/or higher velocity at a given force (i.e. velocity capability) [223]. Assessing the isoinertial force-velocity-power relationship has previously been found valuable to assist in understanding the underlying mechanisms responsible for maximal power output [23, 270] and training adaptations [18, 271]. The vertical jump is a commonly used movement to assess isoinertial leg power because of its simplicity and explosiveness [223]. The kinematics and kinetics of unloaded and loaded jump squats have been found reliable and used to determine the force-velocity-power profiling of the lower limbs neuromuscular system in adults [18, 230, 271]. Previous studies have also used the load-power relationship during vertical jump to determine the "optimal" load for maximal power in adults [223] and athletic children and adolescents [19-21]. However, the variability of the force-velocity-power relationship of an isoinertial loaded protocol in youth is unknown. Monitoring mechanistic adaptations may provide better training information than a single point on a curve (e.g. peak power) since previous studies have demonstrated that profiles may be force or velocity dominant [23] and influenced by the training mode [271]. As considerable changes associated with growth and maturation are likely to influence force, velocity and power output during development (e.g. muscle cross-sectional area, fascicle length) [8], athlete mechanistic profiling from a young age would enhance long term athlete development.

Maximal strength as measured by a one repetition maximum (1RM) is a functional measure of neuromuscular force capability and is usually determined by lifting maximal loads. Recently maximal strength has been predicted based on the load-velocity relationship using a loading protocol [24]. The obvious benefits of this estimation are that submaximal lifting is considered safer for athletes with little weightlifting history such as children and adolescents and the reduction of testing time to reach one maximal lift (7-11 trials) [272] while also assessing the force-velocity-power profile of young athletes [24]. However, the prediction of maximal strength from the load-velocity relationship was undertaken in an adult population and whether maximal strength can be accurately and reliably established in a youth population is unknown.

Using loaded jumps may not be advisable for general pediatric populations due to poor squatting and landing technique, overloading of the growing spine, and increased force during landing [214]. Force-velocity-power profiles of children and adolescents in cycling were found reliable [15, 16] but the validity of such tests for field sport athletes is questionable [9] and does not allow for estimation of maximal strength. Previous studies have demonstrated the safety of ballistic movement on a supine squat machine with novice and experienced weightlifters [22, 23]. As this movement simulates jump mechanics, it could be used to determine the isoinertial force-velocity power profile of youth athletes. Inertial dynamometers (e.g. linear position transducers or accelerometers) have been found to be reliable in combination with this equipment and associated methodologies [22] and have been used with adults to create load-velocity [24] and load-power profiles [273, 274]. However, this methodology is yet to be applied to youth populations. Such analysis would provide a safe method to better understand mechanistic changes during growth, and the influence of maturation on force-velocity-power relationship and profile.

Establishing the reliability of new assessments in novel populations, such as children, is critical to determine the ability of the test to monitor changes in athletic performance over time [251]. The variation in performance can be attributed to biological sources (e.g. changes in an individual jump height between trials because of changes in physical state) or equipment. Establishing the typical variation of performance measures assists coaches and sports scientists in confidently assessing the effects of training interventions by taking into account the changes that are likely due to the 'noise' involved in the testing methods as well as typical daily biological variation present within a group of athletes. Hopkins [251] recommended that a systematic change in the mean as well as measures of absolute and relative consistency (i.e. within-subject variation and retest correlations respectively) be reported to gain a true appreciation of the reliability of a measure/s. Given this information, the purpose of this study was to quantify the inter-session reliability of force-velocity-power profiling in youth using a ballistic loading protocol on a supine leg press. Furthermore, the ability of regression lines to predict maximum power and associated optimal load and velocity, predicted 1RM, as well as maximal force and velocity were also of research interest.

Methods

Subjects

Thirty-six youth males between 11 and 15 years of age volunteered for this study. All participants were nominated by their physical education teacher to be part of a school sports academy. Participant characteristics are presented in Table 5.1. The Human Research Ethics Committee of AUT University approved the study and both the participants and their parents/guardians gave their written consent/assent prior to the start of the study.

Testing procedures

Anthropometric measurements were taken before the first performance testing on the supine squat machine. The standing height (cm), sitting height (cm) and mass (kg) were measured and the body mass index (BMI) calculated. The maturity status of the athletes was determined using years from peak height velocity (i.e. PHV offset) [137] as well as the percentage of predicted adult stature (PAS) [141].

Table 5.1. Subject characteristics

Variables	Mean ± SD
Age (y)	13.1 ± 1.1
Height (cm)	160 ± 10.6
Mass (kg)	49.5 ± 11.6
Leg length (cm)	77.3 ± 5.5
Peak height velocity offset (y)	-0.7 ± 1.2
Predicted adult stature (%)	89.6 ± 5.9
Body mass index (kg.m^{-2})	19.0 ± 2.7
Body Fat (% body mass)	14.8 ± 4.8

Subjects attended three designated testing sessions at the same time of the day separated by seven days. Prior to testing, participants undertook a 15-minute standardized warm-up using the different loads employed in the testing. Performance testing consisted of three trials of ballistic concentric squats on a supine squat machine (Fitness Works,

102

Auckland, New Zealand) at five different relative loads (80%, 100%, 120%, 140% and 160% body mass), performed in a randomised order. The mean of the three trials was used for further analysis. Prior to each load, participants were asked to fully extend their leg to determine the zero position, which was used to determine the end of the pushing phase. A recovery of 30 seconds between trials within load and 120 seconds between loads was given. The sled lay on top of an undercarriage, which enabled the sled to be pegged every 2 cm, allowing standardization of the foot position and knee angle (70°) using a shin position parallel to the ground and goniometer, respectively [22]. The supine squat machine was designed to allow novice participants to perform maximal squats or explosive squat jumps, with the back rigidly supported, thus minimizing the risk associated with such exercises in an upright position (e.g. excessive landing forces, lumbar spine flexion and extension) (Figure 5.1).
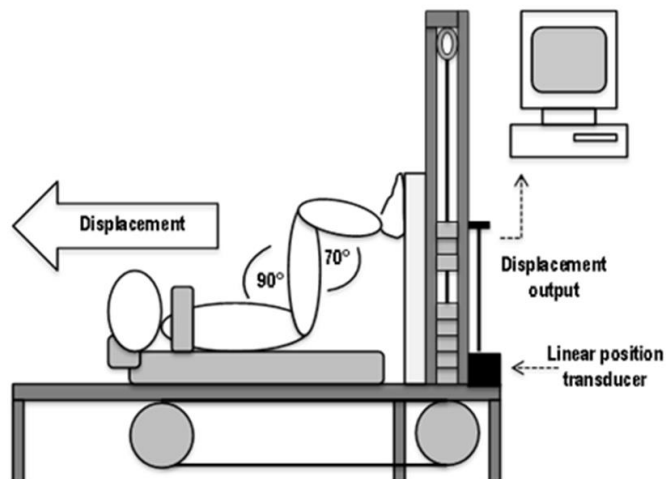
Figure 5.1. Experimental set up on the supine squat machine.
The linear position transducer was attached to the weight stack to provide displacement data as the subject moved horizontally.

A linear position transducer (Celesco, Model PT9510-0150-112-1310, USA) attached to the weight stack measured vertical displacement relative to the ground with an accuracy of 0.1 cm. These data were sampled at 1000 Hz by a computer based data acquisition and analysis program. The displacement-time data were filtered using a low-pass 4th-order Butterworth filter with a cut-off frequency of 50 Hz, to obtain position. The filtered position data were then differentiated using the finite-difference technique to

determine velocity (v) and acceleration (a) data of the weight stack, which were each successively filtered using a low-pass 4th-order Butterworth Filter with a cut-off frequency of 6 Hz [273]. The instantaneous vertical force (F) produced during the thrust was determined by adding the weight of the weight stack to the force required to accelerate the system mass, which consisted of the mass of the weight stack (mWS), the mass of the participant (mP), and the mass of the sled (mS), so F = g(mWS) + a(mWS + mP + mS), where g is the acceleration due to gravity and a is the acceleration generated by the movement of the participant. Following these calculations, power was determined by multiplying the force by velocity at each time point. Average force, velocity and power were determined from the averages of the instantaneous values over the entire push-off phase (until full leg extension, i.e. position 0). The external validity of the derived measurements from a linear position transducer have been quantified using the force plate as a "gold standard" device (r = 0.81-0.96) [259, 260, 275], but the reader needs to be mindful that the linear position transducer has been reported to underestimate force and power output in comparison to force plate data [260].

Data analysis

One-repetition maximum (1RM) was estimated via the load-velocity relationship [24]. The 1RM velocity was not calculated in the current study and this value (0.23 m.s^{-1}) was extracted from previous studies in adults [24, 273] to be plotted on the load-velocity curve to extract 1RM (Figure 5.2). A pilot study on 10 children involved in the current study found a 5% (Confidence limits, CL: 9.5 to 0.2%) underestimation of the actual 1RM (118.5 ± 27.3 kg) when compared to the predicted 1RM at 0.23 m.s^{-1} (112.1 ± 23.0 kg). Pearson correlation of 0.94 (0.80 to 0.98 CL) between the two measures were similar to the findings of Jidovtseff et al. (r = 0.95-0.96) [24].

Force-velocity (F-v) relationships were determined by least-squares linear regressions using average force and velocity at each load. Individual force-velocity slopes were extrapolated to obtain maximal force (Fmax) and velocity (Vmax), which corresponded to the intercepts of the F-v slope with the force and velocity axes respectively [23, 270] (Figure 5.3). Since the power-load and power-velocity relationship is derived from the product of force and velocity, it was logically described by second-degree polynomial functions and maximal power output (Pmax) and the optimal load and velocity

104

at which Pmax occurred was determined using the power-load and power-velocity regression curve, respectively [273]. The goodness-of-fit of the individuals' quadratics was expressed as a correlation coefficient calculated by taking the square root of the fraction of the variance explained by the model, after adjusting for degrees of freedom; the values were then averaged. The curve was also used to estimate the percent decline in Pmax at loads of 10 and 20% of BM either side of the maximum power output.

Statistical analysis

Following data collection, means and standard deviations were calculated for all variables of interest. The three trials for all ballistic squat variables at different loads were averaged for an individual subject mean for each session. To determine the influence of maturity on all dependent variables, initial data analysis was conducted on the individual inter-session coefficient of variation (CV) in all loads. The sample was split into three groups: post-growth spurt (+1.37 to +0.05 years from PHV and 97.7-90.7% PAS; n = 13); in-growth spurt (-0.01 to -1.45 years from PHV and 92.6-85.2% PAS; n = 14); and, pre-growth spurt (-1.66 to -2.67 years from PHV and 85.2-80.9% PAS; n = 9). A one-way analysis of variance (ANOVA) on the CV was conducted to determine any significant difference in reliability across the three groups. Assumptions of normality and homoscedasticity were checked with Shapiro-Wilk and Levene tests, respectively. Since there was no significant difference amongst the groups (P > 0.05), the effect of maturity on reliability was deemed negligible and the data was pooled for further analysis.

The inter-session reliability was calculated using three different statistical methods using pairwise comparisons with 90% confidence limits with log-transformed data to reduce the effects of any non-uniformity of error [251]. The standard error of measurement, expressed as a coefficient of variation (CV), was reported to determine the absolute reliability or within subject variation of the different variables [251]. Percent change in the mean (CM) was reported to indicate the extent to which the average performance changed over testing occasion due to systematic effects (e.g. learning effect) and random effect (e.g. noise) [251] and relative reliability was quantified via an intraclass correlation coefficient (ICC). The level of acceptance for reliability was a CV ≤ 15% [252] and ICC ≥ 0.70 [253]. Reliability comparison of the dependent variables from session 1-2 to 2-3 was investigated by calculating the confidence intervals for the ratio of the CV between sessions, using the

fact that the sampling distribution of the ratio of the sample to population variances in the two groups is an *F*-distribution. We regarded a CV that differed by a factor of 1.15 or more as being substantially different, because the effect of such a difference on sample size in a controlled trial of competitive performance is a factor of 1.15 [255], or a change in sample size of 32%. The chance of "beneficial/better" or "detrimental/poorer" reliability from session to session were assessed qualitatively as follows: 25–75%, possible; 75–95%, likely; 95-99.5%, very likely; >99.5%, most likely. If the probabilities of the effect being substantially positive and negative were both >5%, the effect was reported as unclear [186].

Results

The mean, standard deviation of the kinetics and kinematics across the load of testing session one is presented in Table 5.2. Peak and mean force increased with increasing load, whereas velocity and subsequent displacement decreased. Most of the kinetic and kinematic variables of interest (see Table 5.3) were found reliable across multiple testing occasions for the different loads (CM = 1-14%; CV = 3-18%; ICC = 0.74-0.99). Peak and mean force were the most reliable while peak displacement was the most variable. After comparing CV's between sessions 1-2 and sessions 2-3 it was found that 60% of the variables were classified as likely, very likely or most likely to be more reliable from session 2-3 compared to session 1-2. The loads at 80% and 160% body mass were the most likely to benefit from a third session, with six and four from seven variables improving substantially between sessions 2-3(> 75% of a beneficial outcome).

Table 5.2. Kinematic and kinetic measurements of session one (Mean ± SD) across loads relative to body mass (%)

Variables	80%	100%	120%	140%	160%
Peak force (N)	678 ± 209	744 ± 213	797 ± 229	880 ± 245	940 ± 261
Mean force (N)	539 ± 161	595 ± 164	635 ± 171	691 ± 175	737 ± 190
Peak velocity (m.s^{-1})	1.21 ± 0.17	1.12 ± 0.15	1.00 ± 0.14	0.91 ± 0.14	0.83 ± 0.15
Mean velocity (m.s^{-1})	0.64 ± 0.08	0.57 ± 0.08	0.50 ± 0.08	0.42 ± 0.08	0.37 ± 0.09
Peak power (W)	713 ± 300	735 ± 285	714 ± 284	712 ± 279	710 ± 291
Mean power (W)	362 ± 149	362 ± 138	339 ± 133	315 ± 116	297 ± 126
Peak displacement (cm)	27.2 ± 6.8	21.8 ± 5.1	16.9 ± 4.4	14.2 ± 3.8	11.9 ± 3.9

Table 5.3. Range in reliability statistics for the direct variables of interest from supine squat jump across the five loads

	Change in the mean[a] (%)		Error of measurement[b] (CV%)		Intraclass correlation[c]	
Variables	Sess. 1-2	Sess. 2-3	Sess. 1-2	Sess. 2-3	Sess. 1-2	Sess. 2-3
Peak force	3.4-5.1	1.8-2.4	4.3-5.4	3.0-4.3	0.97-0.98	0.98-0.99
Mean force	2.8-5.4	0.5-2.6	3.2-4.7	2.6-4.0	0.98-0.99	0.98-0.99
Peak velocity	4.1-6.0	1.7-3.6	5.3-8.2	3.1-5.5	0.81-0.86	0.88-0.94
Mean velocity	6.4-12	1.3-3.4	4.6-9.9	5.0-8.4	0.80-0.87	0.77-0.89
Peak power	6.9-9.4	2.7-4.9	10-12	5.7-8.7	0.93-0.94	0.96-0.98
Mean power	11-14	3.1-6.2	8.6-13	6.6-11	0.92-0.95	0.92-0.96
Peak disp.	1.6-11	0.4-8.2	12-18	5.5-12	0.74-0.86	0.84-0.94

[a]90% confidence limits: ± 0.40 * error of measurement = ±(error of measurement)*($\sqrt{2}/\sqrt{n}$)*t; where n is the sample size, and t is the t statistic for 90% confidence limits
[b]90% confidence limits: ÷/×1.20
[c]90% confidence limits: lowest ICC ± 0.13, highest ICC ± 0.01
Sess.: session; disp.: displacement

Mean, standard deviation and reliability statistics of 1RM, Fmax, Vmax, Fmax/Vmax slope, Pmax's (at optimal load and optimal velocity), optimal load and optimal velocity estimations are presented in Table 5.4. Based on the strong load-velocity relationship (mean goodness-of-fit session 2-3 R^2 = 0.99) (see Figure 5.2), 1RM was found reliable and the effect of familiarization unclear (see Table 5.4). Fmax and Vmax, which were derived from the F-v relationship (mean goodness-of-fit third session R^2 = 0.90), were found to be relatively reliable (CM = 0.8-6.9; CV = 7.2-12.4; ICC = 0.57-0.80). Vmax was likely to benefit from a familiarization session and the Fmax/Vmax slope was found unreliable (see Table 5.4).
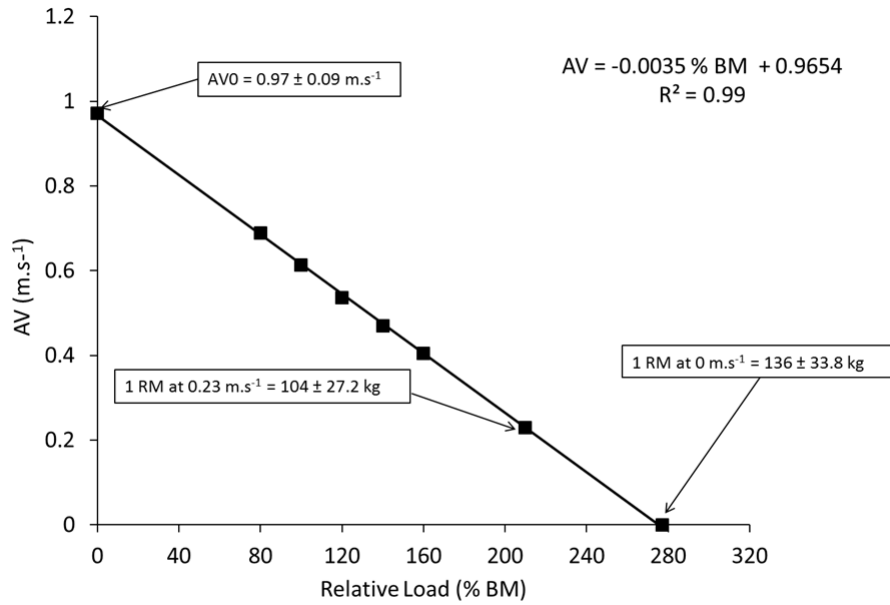
Figure 5.2. Average velocity (AV) - relative load (% body mass - BM) relationship.
The dynamic one repetition maximum (1RM at 0.23 m.s⁻¹), isometric 1RM (1RM at 0 m.s-1) and maximal velocity (AV0) were derived from the load-velocity slope of the mean values between session 2 and 3 observed in the whole sample. The relationship between the two 1RM was r = 0.99.

The reliability of Pmax at optimal load and optimal velocity were acceptable (CM = 4-14%; CV = 6-12%; ICC = 0.91-0.97) but Pmax at optimal velocity was very likely to benefit from a familiarization session. Pmax at optimal velocity and Pmax at optimal load were found to be significantly correlated (r = 0.98; confidence limits: 0.96-0.99). However, only optimal velocity was deemed reliable but was also very likely to benefit from a familiarization session. The mean goodness-of-fit of the power-load and power-velocity curve were R^2 = 0.81 and 0.82, respectively.

Table 5.4. Session one derived variables (mean ± SD) and reliability across the three sessions based on the incremental loading protocol

| Variables | Means ± SD | Change in the mean[a] (%) | | SEM[b] (CV%) | | Intraclass Correlation[c] | |
	Session 1	Session 1-2	Session 2-3	Session 1-2	Session 2-3	Session 1-2	Session 2-3
1RM (kg)	98.1 ± 25.4	5.1	1.6	6.0	6.8	0.95	0.94
Fmax (N)	979 ± 234	4.5	0.8	8.0	7.2	0.71	0.78
Vmax (m.s^{-1})	1.48 ± 0.34	6.9	6.1	16.4	11.2	0.57	0.80
Fmax/Fmax slope	-674 ± 154	3.2	-0.2	24.8	23.6	0.35	0.54
Pmax (W) (P-l slope)	376 ± 150	9.7	4.0	7.9	9.1	0.96	0.94
Pmax (W) (P-v slope)	367 ± 154	13.5	5.6	12.2	6.1	0.91	0.97
Optimal load at Pmax (%BW)	87.6 ± 14.6	2.4	-1.0	13.7	10.2	0.26	0.61
Optimal velocity at Pmax (m.s^{-1})	0.60 ± 0.11	9.2	5.6	13.6	6.7	0.48	0.79

SEM = Standard of error of measurement represented as a coefficient of variation (CV%); 1RM = estimated one repetition maximal; Fmax = estimated maximal force from force-velocity relationship; Vmax = maximal velocity from force-velocity relationship; Fmax/Vmax slope = ratio between Fmax and Vmax; Pmax = maximal power estimation using power-load (P-l slope) or power-velocity (P-v slope)
[a]90% confidence limits: ± 0.40 * error of measurement = ±(error of measurement)*($\sqrt{2}$/$\sqrt{n}$)*t; where n is the sample size, and t is the t statistic for 90% confidence limits
[b]90% confidence limits: ÷/×1.20
[c]Confidence limits: lowest ICC ± 0.26, highest ICC ± 0.02

An estimated load of 87.6% body mass (± 14.6% - session 1) was found to maximize power output. Individual maximal power outputs ranged from 80 to 129% body mass but 50% of the participants had a theoretical optimal load less than 80% body mass. Figure 5.3 highlights the difference between two participants with different F-v and power-velocity relationships. A 10 and 20% change in load each side of this maximum resulted in a 2.2 and 5.5% decrease in power output, respectively.
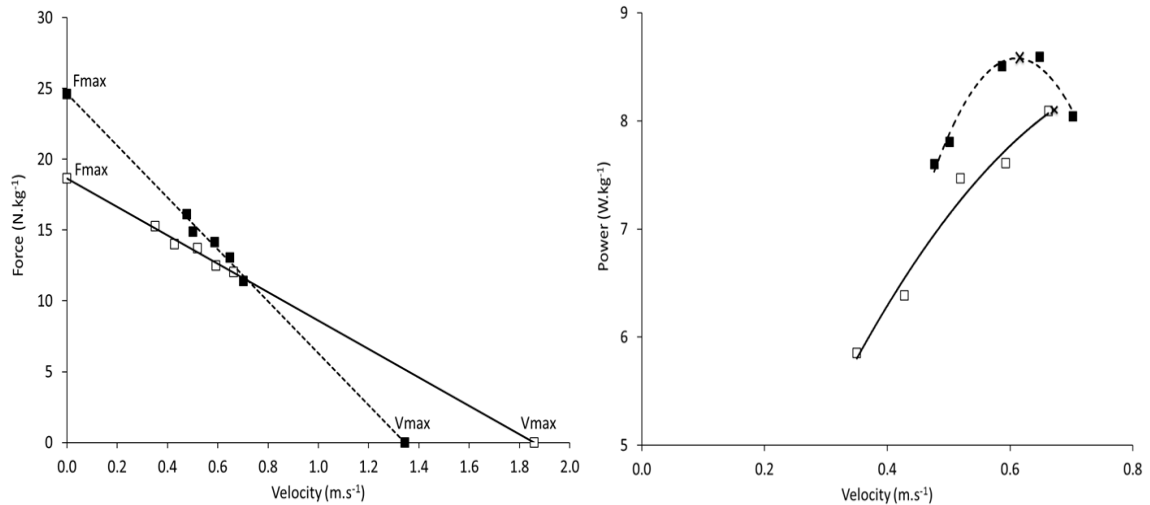
Figure 5.3. Typical force–velocity (F-v) (*left panel*) and power–velocity (*right panel*) relationships for two subjects with different F–v profiles and maximal power values (*gray cross*).
Subject 1 (*open squares*) presents a lower maximal power and an F–v profile more oriented toward velocity capabilities than subject 2 (*filled squares*), who presents an F–v profile more oriented toward force capabilities.

Discussion

The aim of the current study was to determine the variability of a new isoinertial protocol to assess force-velocity-power and maximal strength in a paediatric population. The intersession reliability of the kinematics and kinetics from the isoinertial loaded ballistic supine squats was deemed acceptable. Similar reliability statistics (CM = -1 to 5%; CV = 3-10%; ICC = 0.71-0.95) have been reported in research with adults [230]. Previous studies in youth have shown that the jump height variability increased during an incremental loading protocol from unloaded to 40 kg [19]. This trend was echoed in the current study, as poorer yet acceptable reliability, was found at the 160% body mass load and the most reliable data was recorded at body mass. However, when the load became lower than body mass (80%), the reliability was also affected. It can be concluded that increased biological

variability in young athletes occurred when movement velocity or force requirements were high and influenced by learning. It is recommended that an in-depth familiarisation across the load spectrum should be conducted, after which force-velocity-power profiling in youth can be confidently implemented to monitor mechanistic determinants of movement during growth and maturation.

It was observed that predicted 1RM at 0.23 m.s^{-1} was reliable and unaffected by biological variation on the contrary to the study of Cronin et al. [22], which demonstrated a significant improvement in maximal strength by as much as 15% from the first to the fourth 1RM testing occasion in novice weight trainers. The prediction based on load-velocity relationship therefore seemed to be less affected by learning compared to regular 1RM testing. The 1RM at 0 m.s^{-1} was 30% higher compared to the dynamic 1RM at 0.23 m.s^{-1} (Figure 5.2), which was in accordance with the knowledge of greater maximum isometric force compared to maximum concentric force based on the F-v relationship [276]. Jidovtseff et al. [24] reported a smaller difference between estimated 1RM at 0 m.s^{-1} from the load-velocity relationship and actual 1RM (16%) in comparison to this study (30%). Given the results of our pilot study, estimated 1RM at 0.23 m.s^{-1} could underestimate actual 1RM by 5% in the current population, which could explain partly the difference between the two studies as Jidovtseff et al. [24] used completed 1RM as a reference. The type of population tested (adults vs. children) and the difference in the movement performed (bench press vs. supine squat machine) may have also affected the load-velocity slope, possibly resulting in greater differences between 1RM at 0 m.s^{-1} and 0.23 m.s^{-1} in the current study. The reader must be mindful of these limitations when using estimated 1RM and should established the velocity at 1RM with the specific test used. However, the high correlation (r = 0.94) and minimal absolute difference (5%) between estimated 1RM at 0.23 m.s^{-1} and true 1RM in our pilot study would suggest that the estimated 1RM is a representative measure of maximal strength. In addition, considering its reliability as well as the multiple diagnostic benefits of the incremental loading protocol, such an approach is an intuitively appealing strategy for the assessment and monitoring of young athletes.

The mechanical limits of skeletal muscles' contractile elements are represented by an inverse linear F-v relationship, which account for the decreased capability of the lower extremities to generate force with increasing movement velocity [269, 271]. Such a relationship was evidenced in the youth population investigated in this study (Figure 5.3). Fmax and Vmax derived from this relationship were found reliable on testing sessions 2-3

111

but Vmax was likely to be influenced by familiarization and considered unreliable from sessions 1-2 (i.e. biological variation). Given the importance of these two fundamental mechanical entities for jumping [277, 278], a minimum of one familiarization is recommended.

The F-v mechanical profile of the lower limbs can be represented by the slope of Fmax/Vmax with the force graphically represented on the vertical axis of the F-v relationship (Figure 5.3). The steeper the F-v relationship, the more force dominant the athlete is [23]. Due to the variability of average force and velocity and subsequent error of Vmax and Fmax estimation, the slope appeared unreliable. Therefore, the application of this ratio needs to be used with caution considering the large variability associated with it. It is possible that direct measurement of force (e.g. force plate) and velocity (e.g. tachometer) would reduce the variability associated with the slope. This study was the first to report the reliability of this measure and therefore further investigations regarding the reliability and utility of this measurement in youth is warranted.

The Pmax achieved during ballistic movement across a load spectrum and associated recommendations for optimal loading have been widely investigated in the literature [223]. Only reporting the actual load lifted at Pmax may be misleading and recent studies have fitted quadratic equations to the power-load curve to estimate Pmax and optimal load during multi-joint exercises (mean R^2 = 0.75- 0.94) [273, 274]. The current study found a similar goodness-of-fit of the power-load curve (R^2 = 0.81). Pmax estimation was thought reliable and the effect of a familiarisation session was deemed minimal. In contrast to the findings of Harris et al. [273] (CV = 5.7-6.2%; ICC = 0.86-0.92), the optimal load that maximized power output was found unreliable across all testing occasions. The difference between studies may be explained by the movement, loading parameters and participants age being different. Also, the reliability statistics reported by Harris et al. [273] were only conducted within a single session, which only provides minimal insight data variability. The variability around the load that maximized power output in this study was most likely explained by the relative low biological variance in power output across the loading spectrum where a 10 and 20% change either side of the optimal load corresponded to a 1 to 6% change in Pmax. Both Harris et al. [273] and Cronin et al. [274] found a similar variance around Pmax (1 to 7%) with a 10 and 20% change in optimal load, which demonstrates that load spectrum rather than specific load can be targeted for Pmax output, regardless of the type of assessment or population.

Using the group means, 88% body mass as the optimal load was equal to 41% estimated 1RM. Considering that 50% of the participants theoretical load was beyond the load spectrum (<80% body mass), the estimated optimal load in the current study was in accordance with bench press optimal load (30-45% 1RM) where only the external load is projected [223]. The later point is imperative when the relationship between the supine leg press squat jump power and regular squat jump power output is considered. On one hand, during a traditional squat jump, not all body parts are similarly accelerated (e.g. the lower legs are less accelerated than the upper body) and thus the mean accelerated mass and corresponding resistance force is less than body mass and varies throughout the acceleration phase. On the other hand, under the simulated 100% body mass in the supine leg press squat jump, the subject accelerates 100% of body mass in the form of the weighted plates in addition to the body mass and sled, which make the total force required above regular body mass. This limitation may explain partly why optimal load was below body mass on the supine squat machine, whereas the optimal load to maximize power output during a regular squat jump is considered to be body mass [223]. From a validity perspective, the relationship between peak power obtained during a vertical squat jump and the supine squat jump at 100% body mass load with the current participants in a pilot study was 0.89 (0.83-0.94, ninety percent confidence limit) and would support the utilization of the supine leg press in novice participants [279].

With the accessibility of inertial dynamometers (LPT or accelerometer), training at a specific velocity or optimal velocity to target Pmax has become common practice in high performance sport [280, 281]. We found that estimating Pmax based on the power-velocity curve was reliable but very likely to most likely to benefit from a familiarization session. Mean goodness-of-fit from the curve ($R^2 = 0.84$) was similar to previous findings [23, 270, 279] ($R^2 = 0.70$-0.99). Therefore, using the power-velocity curve to estimate Pmax and the optimal velocity to achieve Pmax is appealing. From an applied perspective, Randall et al. [281] demonstrated the benefit of instantaneous feedback on achieving pre-specified threshold velocities for power training. Therefore, using optimal velocity as biofeedback during sessions is one manner in which the sport scientist can optimize training design and adaptations.

Conclusion

The intersession kinematics and kinetics of a ballistic loading protocol using an instrumented (LPT) supine squat machine were found reliable in a youth population. Considering the unconventional nature of performing such movements in a horizontal position as well as explosively overcoming resistance greater or lower than body mass, a familiarization session was likely to provide more reliable data by reducing biological variation and should be conducted across the entire load spectrum. The strong load-velocity relationship appeared to be an excellent alternative to standard 1RM testing, and could be a preferred method to determine maximal strength for untrained or youth populations. Furthermore, the ballistic loading protocol provided additional information about the neuromuscular characteristics of the young athlete. The F-v relationship provides a useful tool to better explore force and velocity specificity adaptation resulting from different loading and subsequent training velocities. Also, both the power-load and power-velocity relationships can be calculated relatively quickly and reliably, and can be used to predict Pmax as well as informing loading parameters and movement velocity in training programs aiming at enhancing power output. Since growth and maturation are likely to affect both maximal force and velocity of movement, future research should investigate the influence of maturity as well as the efficacy of different training programs on the force-velocity-power profile of youth during isoinertial ballistic movement.

Chapter 6: Sex-related differences in explosive actions during late childhood

Prelude

Based on the previous chapters, it was determined that peak power during jumping can be used reliability across different maturity status to track changes due to both training and natural development. To reduce the advantage of greater size when comparing athletes of different maturity status, power should be scaled appropriately for body mass. Power production is required in a multitude of explosive actions in sports but rather than maximal power per se, some of these actions such as maximal running velocity and agility may require more of a high rate of power development and velocity of movement. The differences in the performance of explosive actions during growth may be dictated by maturity-related characteristics. Since genders have independent timing and tempo of maturation, the onset of sex differences in various explosive activities may change depending on the dominant qualities required in the task. This difference in maturation between sexes may also create differences between genders in predictive maturity and anthropometric factors of performance. In the context of this literature, the purpose of this study was to examine sex-related differences in explosive actions during late childhood, while accounting for body size and maturity, and to determine the predictors responsible for explosive performance.

Introduction

In modern team sports (e.g. soccer, field hockey, basketball, rugby) physical development considerations are increasingly essential to optimize performance, not only in adults, but also in children. Initial acceleration (0-10 m), maximal velocity (10-30 m), jumping, or changes of direction (COD) are various explosive actions, which may influence the game outcome [153] and should be developed from a young age [2]. Towards these ends, physical testing (e.g. anthropometric characteristics, explosive actions) is usually part of a comprehensive multidisciplinary approach in talent identification and development [3]. To overcome the current pitfalls in talent identification and development (e.g. relative age effect) and obtain a clearer diagnosis of physical performance, data analysis needs to account or scale for maturity differences and determine the role of quantitative (i.e. body size) and qualitative (i.e. body tissue and structure) characteristics in performance [282]. The objective of scaling is to produce a "size free" variable. Traditional ratio scaling (e.g. power/body mass) often fails to produce a body dimensionless index and allometric scaling (e.g. power/mass^b) is commonly accepted as a better method to scale for body mass [35]. Specific theoretical scaling models for force or power have been suggested [283], however, to accurately account for body mass, both subject and test specific *b* exponents must be applied [35]. Power assessment using jumping protocols is widely used and validated in adult athletic populations [227] and has been found reliable in children [284]. Previous researchers [176, 282] have investigated power output and its related scaling issues in children using cycle ergometer testing, but to our knowledge, no research has investigated these issues during jumping. Considering the full body mass bearing and various planes of force production in most sports, assessing and monitoring both vertical and horizontal peak power would be relevant to youth programs.

It is well known that muscles produce maximal power output against an optimal external load [223]. Jaric and Markovic [285] have developed the *maximum dynamic output* hypothesis, suggesting that maximal power output during most athletic movements occurs at body mass. If body mass represents the optimal load for peak power output in weight bearing activities, force production, motor control and movement velocity are task dependent. The neuromuscular specificity of various explosive actions (e.g. sprinting, vertical jump, plate tapping) were found to result in different peak performance velocity curves in relation to peak height velocity (PHV) [6, 179]. These accelerated periods of

performance change in sprinting, vertical jumping or plate tapping may create different relationships or transference between skills as compared to adults as well as different onset of sex differences depending on the explosive task. During growth, girls reach PHV about two years prior to boys (around 11.5 and 13.7 years old, respectively) [52]. The sex specific timing of maturation [96] as well as the gender differences in morphological and neuromuscular characteristics may lead to early or delayed onset of sex related difference in explosive actions. Investigating such contentions may provide practitioners with a greater understanding of sex specific development of explosive actions and guide gender specific athletic development programs. However, the onset of sex related differences in explosive actions (i.e. speed, change of direction, jump) requiring different movement pattern and velocities is yet to be addressed.

Furthermore, the investigation of sex specific predictive morphological and maturation factors to various explosive actions may offer insight into the underlying mechanisms responsible for gender differences in athletic performance [4] and disentangle the most relevant anthropometric and maturity related variables to track talent development. Given the gap in the current literature and its relevance to youth athletic development, the purposes of this study were to: first determine population and test specific allometric exponents of leg power to allow an accurate comparison between individuals of different sizes; second, to identify the differences between sexes in explosive actions; and, third, define the role of maturity and anthropometric characteristics in performance.

Methods

Experimental approach of the problem

A cross-sectional design was used to determine the difference in explosive actions between boys and girls, aged 9-12 years old. Sixty-eight boys and 45 girls performed a vertical countermovement jump (VCMJ), horizontal countermovement jump (HCMJ), 30 m sprint and COD time trial. Power measures were allometrically scaled to body mass to account for body size and all performance variables were adjusted for maturity before addressing sex related differences due to the variance in the onset of puberty between genders. To further understand the role of subject characteristics in explosive performance and discrepancies between sexes, predictive models of explosive performance were created for both genders.

117

Subjects

Sixty-eight male and 45 female athletes between 9 and 12 years of age from a sport program volunteered for this study. All children were nominated by their school as outstanding athletes to be involved in this program and were training/competing on average 7.6 ± 2.2 (girls - G) hours and 7.3 ± 2.1 (boys - B) per week in various sports. The physical activity, which was expressed as hours per subject per week for each sex (in brackets), included multi-sport activity such as physical education (G: 4.0; B: 3.4), soccer (G: 0.1; B: 1.0), rugby (G: 0.00; B: 0.2), cricket (G: 0.0; B: 1.2), basketball (G: 0.2; B: 0.3), netball (G: 0.1; B: 0.0), touch rugby (G: 0.5; B: 0.0), field hockey (G: 0.2; B:0.1), athletics (G: 0.3; B: 0.3), water-polo (G: 0.2; B: 0.2), swimming (G:0.3; B: 0.3) and surf-life saving (G: 1.0; B: 0.3). Participant characteristics are presented in Table 6.1. All testing procedures and risks were fully explained to the subjects and their parents/guardians. Both the subjects and their parents/guardians gave their written consent prior to the start of the study, which was approved by the Human Research Ethics Committee of AUT University.

Table 6.1. Subject characteristics (mean ± SD)

Variables	Boys (N = 68)	Girls (N = 45)
Age (y)	11.0 ± 1.1	11.3 ± 0.9
Age at PHV (y)	13.4 ± 0.5*	11. 9 ± 0.5
PHV offset (y)	-2.6 ± 0.8	-0.6 ± 0.9*
Predicted adult height (%)	81.9 ± 3.7	89.4 ± 4.1*
Height (cm)	147 ± 8.3	149 ± 8.7
Mass (kg)	38.6 ± 7.3	40.0 ± 8.0
Leg Length (cm)	69.7 ± 5.4	72.2 ± 5.2*
Sum 4 skinfolds (mm)	32.1 ± 10.0	36.2 ± 13.4
Somatotype		
Endomorph	2.6 ± 0.9	3.0 ± 1.1
Mesomorph	4.4 ± 1.0*	3.8 ± 1.2
Ectomorph	3.4 ± 1.1	3.6 ± 1.4

* greater than the other gender ($p < 0.05$); PHV: peak height velocity

Testing procedures

Subjects attended one designated testing session preceded by a familiarization of all testing procedures. Anthropometric measurements were taken before performance testing. The standing height (cm), sitting height (cm) and mass (kg) were measured and skinfolds (mm) were taken at four sites: triceps, subscapular, supraspinale and medial calf, using a skinfold Slim Guide caliper (nearest 0.5 mm). The girth (cm) of calf and arm flexed and tensed were measured as well as the breadth (cm) of biepicondylar humerus and biepicondylar femur. All measurements were performed following the International Society for the Advancement of Kinanthropometry protocol [286]. Afterwards, somatotypes were calculated according to the methods of Carter [244]. The maturity status of the athletes was determined using years from peak height velocity (PHV offset) calculated with the equation of Mirwald et al. [137]. Since an error of measurement of ± 0.5 years can occur (95% confidence interval) in this equation [137], percentage of predicted adult stature (PAS) was calculated using the method of Khamis and Roche [141] and used as an additional factor to identify the athletes' maturity status.

After the anthropometric measurements, subjects undertook a 10 min standardized warm-up split into a 5-min dynamic range of motion and muscle activation (e.g. lunge and twist, single leg Romanian deadlift, downward dogs) phase followed by 5-min of progressive explosive actions (e.g. skipping, bounding/jumping, sprinting). Subjects performed three trials of a VCMJ and HCMJ, 30 m sprint and change of direction (COD) task in the preceding order. The mean of the three trials was used for further analysis. VCMJ and HCMJ were performed with hands on hips. No specific instructions were given to the participants in regards to the depth or speed of the countermovement but participants were instructed to jump as high or far as possible. The VCMJ started from a standing position and consisted of dynamic flexion at the hip, knee and ankle and then extension until takeoff and landing on two feet in the same place. For the HCMJ, the same starting protocol as the VCMJ was used but the participants jumped as far as possible and were instructed to stick their landing on two feet. Vertical and anterior-posterior (i.e. horizontal) ground reaction force (GRF) data were collected with a portable plate (AMTI, ACP, Watertown, MA) using a sampling rate of 400 Hz during the VCMJ and HCMJ. Jump height, peak vertical and peak horizontal power calculations were provided by the original software manufacturer (AccuPower, Version 1.5, Athletic Republic, Fargo, ND) and have

been described elsewhere [284]. Jump length was measured from the starting line (toes just behind the line) to the heel closest to the starting line at landing.

The 30 m sprint and COD task were conducted on a rubber indoor surface. Both tasks were measured with timing lights consisting of a dual-beam modulated visible red-light system with polarizing filters (Swift Performance Equipment, Walcol, Australia). Subjects were asked to start in a still split stance with the preferred leg forward 30 cm behind the starting line. Sprint times were measured at 10-20-30 m. Ten meter sprint time was defined as acceleration, while 20 and 30 m split time were considered as maximal velocity. The COD task was split into three components: Zigzag, backwards/sideways and 10 m fly sprint sections (see Figure 6.1). The reliability of the variables used in this study have been reported previously in youth population and found acceptable (intraclass correlations: 0.72 to 0.94; coefficient of variations: 1.6 to 10.6%; % change in the means: -4.4% to 12.3%) [49, 284, 287].
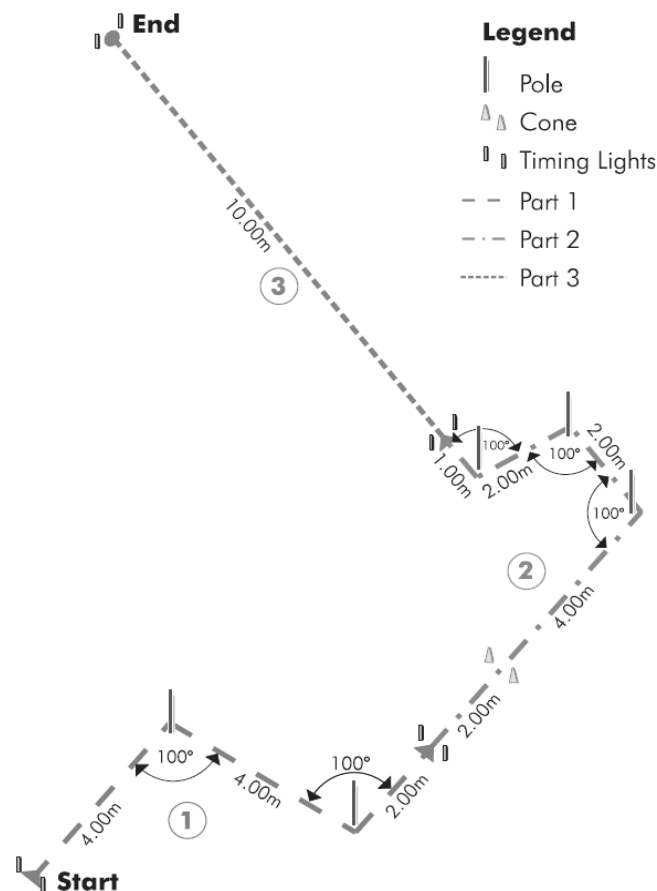
Figure 6.1. Agility course
Part 1: 10 meter (2 x 4 meter and 1 x 2 m) with two-100° turns; Part 2: 2 meter straight sprint section, a turn into backwards running section (4 meter), 2 x 2 meter side-steps sections with two 100° turns, and a 1 meter straight sprint section; Part 3: 10 meter straight sprint.

Statistical analysis

After data collection, means and SDs were calculated for all the results. The distribution of each variable was examined using the Kolmogorov-Smirnov normality test. To account for body mass in power output during VCMJ and HCMJ, logarithmic transformation was applied to the dependent (i.e. horizontal and vertical power) and independent (i.e. body mass) variables to determine allometric relationships. Allometric model ($y = a.x^b$) was linearized by taking natural logarithms (ln) of both sides (lny = lna + b lnx) where *y* is the dependent variable, *b* is the slope of the log-log plot, *a is* the antilog of the *y* intercept and *x* is the independent variable. Initially, separate log linear regressions were conducted for boys and girls. Commonality of slopes of the relationship between body mass and power output between boys and girls was tested, together with a sex-by ln body mass interaction term, in a multiple, log linearized regression model. A non-significant interaction term ($P > 0.05$) confirmed the similarity of slopes between boys and girls and a mass exponent common to boys and girls was then fitted. All exponents were calculated as means $\pm$ SE, allowing construction of 90% confidence intervals. Using the derived mass exponent (b), a power function ratio (i.e. power/mass^b) was constructed [288].

Initially independent sample t-tests were used to determine sex-dependent differences in anthropometric and physical performance characteristics. To address the difference in maturity between sex at this age and its potential influence on performance measures, analyses of covariance (ANCOVA) with maturity as a co-variate was then used to compare sex physical performance. The differences between sexes with maturity as a co-variate were also assessed for mechanistic inferences using an approach based on the magnitudes of change [186]. Threshold values for Cohen ES statistics were 0.2 (small), 0.6 (moderate), 1.2 (large), 2.0 (very large), 4.0 (nearly perfect) and > 4.0 (infinite) [289]. The chance that the true (unknown) values that a sex was "better" (i.e., greater than the smallest practically important effect or the smallest worthwhile change (0.2 multiplied by the between-subject standard deviation, based on Cohen ES principle) [290], unclear or worse in a performance measure was calculated. Quantitative chances of beneficial/better or detrimental/poorer effect were assessed qualitatively as follows: < 1%, almost certainly not; 1–5%, very unlikely; 5–25%, unlikely; 25–75%, possible; 75–95%, likely; 95–99%, very likely; and > 99%, almost certain. If the chance of having beneficial/better or

detrimental/poorer performances was both > 10%, the true difference was assessed as unclear [186].

Pearson product moment correlations were used to determine the relationships between performance variables. Pearson correlations were qualified as trivial (0-0.1), small (0.1-0.3), moderate (0.3-0.5), large (0.5-0.7), very large (0.7-0.9), nearly perfect (0.9) and perfect (1) [289]. To identify anthropometric factors in sexes that were important in athletic performance, multiple linear stepwise regression analyses were conducted. From this analysis, the best multiple-predictor models for 20 m sprint time, COD task, jump height and jump length were derived using age, maturity status and anthropometric characteristics. Regression diagnostics were used to determine whether any outliers were present, whether the data were normally distributed, and whether there were any issues with multicollinearity. The forward stepwise regression began with no variables in the equation and thereafter entered the most "significant' predictor at the first step and continued to add or delete variables until none "significantly" improved the fit. Minimum tolerance for entry into the model and alpha-to-enter/remove were set at 0.05 and 0.10 respectively. An alpha level of 0.05 was used for all statistical test.

Results

Subject characteristics are shown in Table 6.1. No significant differences between sexes were found for age, mass, height, sum of skinfold, endomorphy, ectomorphy and weekly training hours. Significant differences were found in maturity markers (i.e. years from PHV, age at PHV, % adult stature and leg length) as well as mesomorphy. A mass exponent common to boys and girls was found for vertical ($b = 1.02$; CI = 0.92-1.12) and horizontal ($b = 0.97$; CI = 0.76-1.18) power (Figure 6.2).
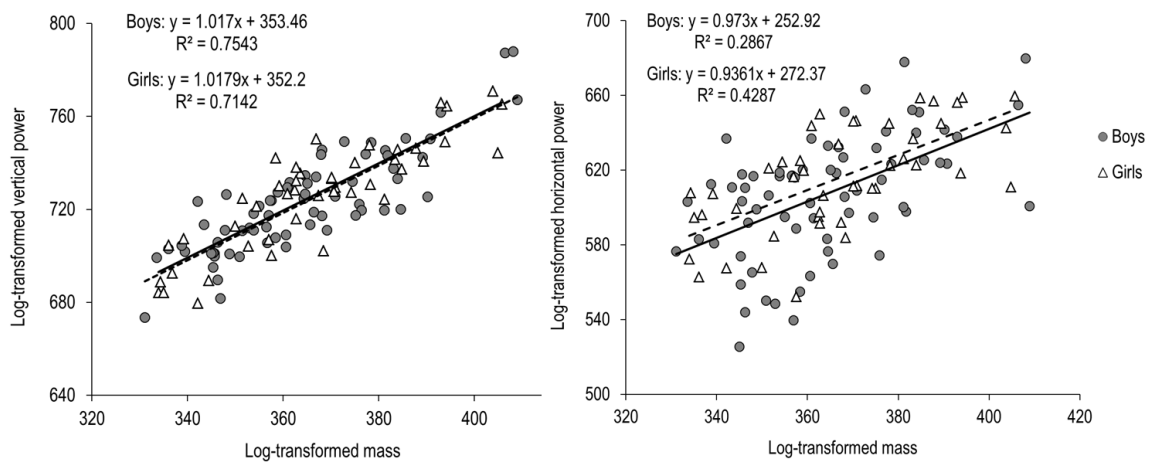
Figure 6.2. Log linear relationship between vertical power and body mass *(left panel)* and horizontal power and body mass *(right panel)* in boys (solid line, P < 0.05) and girls (dash line; P < 0.05).

Data comparing sexes in the performance measures of interest are presented in Table 6.2. Differences in VCMJ and HCMJ variables (i.e. jump height/length and power) between sexes were found non-significant and unclear even when maturity was adjusted for, except for horizontal jump length where a likely small ES ($P = 0.04$) for boys to be better than girls at a given maturity was found. During sprinting, sex differences were possibly small in acceleration (i.e. 10 m) ($P = 0.11$) but there was a likely small chance that boys were better than girls in the 20 m ($P = 0.04$) and 30 m ($P = 0.03$) despite a less advanced maturity status. When results were adjusted for maturity, there was a significant (P < 0.05) and very likely moderate to possibly large chance that boys were better than girls in all sprint times. In terms of COD, there was a likely small chance ($P = 0.02$) that boys would complete the course faster while less mature. The likely small difference in the COD task ($P = 0.01$) between sex was mostly expressed in the backwards/sideways section where the difference between sex was very likely small as compared to the possibly trivial to possibly small outcome differences in sex during the Zigzag and final 10 m section ($P >$ 0.05). For a given maturity, the chance that boys were faster than girls for the different COD split times was possibly moderate to very likely moderate (P < 0.05).

Table 6.2. Sex comparisons (mean ± SD) in performance measures before and after maturity adjustment

Variables	Boys	Girls	Difference between sex[a] (90% CL) standardized effect	
			maturity n-adjusted	maturity adjusted
VCMJ (W/kg$^{1.02}$)	33.8 ± 3.9	34.1 ± 3.9	- 0.9% (-4.7, 2.7) unclear	- 0.2% (-5.9, 5.2) unclear
VCMJ height (cm)	23.9 ± 3.7	24.2 ± 3.8	- 1.1% (-6.3, 3.8) unclear	3.1% (-4.4, 10.1) unclear
HCMJ power (W/kg$^{0.97}$)	13.2 ± 3.5	13.8 ± 2.8	- 6.1% (-14.5, 1.7) possibly small	- 4.6% (-17.2, 6.6) unclear
HCMJ length (cm)	142 ± 17	144 ± 15	- 1.0% (-5.0, -2.8) unclear	6.4%* (-1.1, 11.3) likely small
10 m sprint time (s)	2.16 ± 0.10	2.18 ± 0.09	1.3% (-0.1, 2.6) possibly small	4.5%* (2.5, 6.4) very likely moderate
20 m sprint time (s)	3.76 ± 0.20	3.82 ± 0.17	1.8%* (0.3, 3.4) likely small	5.7%* (3.5, 7.9) possibly large
30 m sprint time (s)	5.32 ± 0.31	5.44 ± 0.27	2.2%* (0.5, 3.9) likely small	6.9%* (4.5, 9.4) possibly large
COD agility time (s)	4.00 ± 0.24	4.07 ± 0.23	1.9% (-0.1, 4.0) possibly small	3.8%* (0.8, 6.9) possibly moderate
BKW/SDW agility time (s)	4.77 ± 0.39	4.99 ± 0.38	4.5%* (1.7, 7.4) very likely small	8.9%* (4.7, 13.3) very likely moderate
10 m agility time (s)	2.09 ± 0.11	2.11 ± 0.10	0.9% (-0.9, 2.7) possibly trivial	4.2%* (1.6, 6.8) likely moderate
Agility total time (s)	10.86 ± 0.66	11.17 ± 0.61	2.8* (0.8, 4.9) likely small	6.1%* (3.1, 9.2) likely moderate

[a]Positive % difference between gender indicates superior performance from boys

*$P < 0.05$; CL: confidence limits; n-adjusted: non-adjusted; VCMJ: vertical countermovement jump; HCMJ : horizontal countermovement jump; COD: change of direction; BKW/SDW: backward and sideways; standardized effect: < 0.2 (trivial), 0.2 (small), 0.6 (moderate), 1.2 (large), 2.0 (very large), 4.0 (nearly perfect) and > 4.0 (infinite).

Based on the large to very large correlations between sprint split times ($r = 0.93$ to 0.99), COD section times ($r = 0.68$ to 0.95) and peak power and jump performance ($r = 0.73$ to 0.80), 20 m sprint, the COD total time, jump height and jump length were selected for the multiple regression analysis. For the females, body mass explained 19% of the variance in the 20 m sprint time while PHV offset, and age still had a significant correlation to the 20 m sprint time but did not add to the predictive model ($P = 0.007$ and 0.01, respectively). Age explained 15% of the variance of the COD time, with hours of training significantly correlated to the dependent variable but not adding to the model ($P = 0.03$). Only 16% of the variance in jump length could be explained by maturity while no significant predictor for jump height was found. Body type seemed to be a determinant factor in boys as reduced endomorphy predicted between 7% and 22% of the explosive performance, while age added significantly to the model to predict 20 m sprint time (30%), COD total time (24%) and jump length (20%). Other independent variables were able to

explain up to 36% of the shared variance in the 20 m sprint time and 39% in COD time in boys (Table 6.3).

Table 6.3. Predictors of explosive performance in boys and girls

Variables	Sex	P. 1	R^2	AR^2	P. 2	R	AR^2	P. 3	R	AR^2	P. 4	R	AR^2	P. 5	R	AR^2
20 m sprint time	Boys	Endo.	0.24	0.22	Age	0.31	0.30	Meso.	0.39	0.36						
	Girls	BM	0.22	0.19												
Agility test time	Boys	Endo.	0.19	0.18	Age	0.26	0.24	T.H.	0.34	0.30	PHVoffset	0.40	0.34	Ecto.	0.45	0.39
	Girls	Age	0.18	0.15												
Jump height	Boys	Endo.	0.09	0.07												
	Girls	N/a														
Jump length	Male	Endo.	0.13	0.11	Age	0.23	0.20									
	Girls	PHVoffset	0.18	0.16												

P.: Predictor; AR: adjusted R^2 to sample size; PHVoffset: maturity status based on years from peak height velocity; Endo.: endomorph somatotype; Ecto.: ectomorph somatotype; T.H.: training hours

Discussion

This study was the first to demonstrate that a common sex allometric scaling factor for body mass in vertical and horizontal power output can be used. The difference in explosive actions between sex was dependent on test specific neuromuscular requirements as no difference prior to male PHV was found in jump power and acceleration but was evident in maximal speed and COD characteristics. These differences in explosive actions were also reflected in the dissimilar morphological and maturity related predictors of performance.

In order to compare athlete power output relative to size, scaling to body mass to produce a "size free" power output measure must be used. As reported by other researchers [37, 288, 291], a common exponent was found between sexes and used to scale vertical and horizontal power output to body mass. The *b* exponent of 1.02 and 0.97 for vertical and horizontal jump, respectively, was dissimilar to the expected theoretical value of 0.67 [283]. However, the current findings are in line with previous research investigating allometric scaling of power output for body mass during VCMJ (*b* = 0.90) [263] and cycling in adults (*b* = 0.92) [37] and children (*b* = 0.84 to 0.97) [15] and therefore demonstrated that allometric scaling should not be based on the presumption of similar body dimensions but should rather be sample and test specific [35]. Once the appropriate allometric scaling factor was applied, both vertical and horizontal power scaled to body mass had a very large relationship to the respective jump outcome (i.e. height or length) in both sexes (*r* = 0.73 to 0.80). Therefore, as argued already in adults [263], jump performance could be considered a body size independent index of muscle power *per se* in children and used in practical settings when a force plate is not accessible. Furthemore, to determine an athlete's power profile, both vertical and horizontal power production should be assessed given the low shared variance between VMCJ and HCMJ (R^2 = 18% to 48%) found in this study and the dissimilar joint kinematics and kinetics [234], electromyographic activity [233] and force production [229].

Sex differences in vertical jump performance have been associated with the appearance of significant differences in lean body mass [111, 292] and subsequent changes in force production at the age of 13-14 years, which has been attributed to the dramatic increase in sex steroid concentrations in males [293]. It was found in this study that when maturity was controlled for, differences between sexes in jump power and performance still remained unclear apart from jump length. Given the age range and maturity status (i.e. boys

127

pre PHV), the current findings seem to confirm that the onset of sex related differences in jump power are likely to appear after males reach PHV [111, 292].

The similar jump power profile between sexes did not result in similar performances across other explosive actions. Differences in acceleration times between sexes remained trivial to possibly small, but 20 to 30 m split times differences were likely small to even possibly large once maturity was accounted for. Power output is an integral component of both acceleration and maximal speed, however, other factors such as inter-muscular coordination, movement velocity and direction or rate of power development are likely to influence these two components of speed to a different degree [198]. The centre of mass is lower and the ground contact time longer during the acceleration phase compared to maximal velocity, resulting in a slower stretch-shortening cycle and rate of power production similar to the CMJ [227], while maximum speed is associated with fast stretch-shortening cycle, lower-limb stiffness and greater hip extensor activity [294]. Therefore, the similar leg power capabilities may explain the minimal difference between sexes in acceleration but other neuromuscular characteristics seem responsible for the differences between sex in the maximal speed performance.

Comparable to maximal speed, the standardized effect between sexes after adjustment for maturity was possibly to very likely moderate in the COD task, in particular the Zigzag and backwards/sideways sections. Several factors could explain the earlier onset of sex related differences in maximal speed and COD performances in comparison to jump power and acceleration. Previous researchers [136, 179] have highlighted the earlier performance spurt in sprint performance and speed of limb movement (i.e. plate tapping) (Pre-PHV) compared to leg power (Mid/Post-PHV). Given the average PHV offset of the current sample (Table 6.1), it can be hypothesized that both sexes have entered or passed the performance velocity spurt for sprint performance and speed of limb movement, however, not so for leg power. Previous studies in cycling [4, 15, 282] have also demonstrated that differences between sexes in optimal velocity for peak power output was observed in 10 years old while difference in optimal force for peak power did not appear before male puberty. Despite the fact that the contraction type and weight bearing differ between cycling and sprinting or COD, velocity capability from one activity to the other could well transfer. This difference in muscle contraction velocity may be explained by sex specific qualitative muscular factors related to contracting velocity (e.g. fibre type distribution, glycolytic enzymes activity, electro-mechanical characteristics) [37, 291].

According to Newton's second law, acceleration can either be enhanced by producing a greater force in the direction of motion or reducing the mass to be moved. No strength measurements were taken in this study but body composition measurements and subsequent calculation of somatotype were conducted. Boys were found to be significantly more muscular than girls (i.e. mesomorphic) and less endomorphic. The current sample included girls that were past their PHV and had entered puberty, a period during which adipose tissue differences between sexes begins to appear [52]. It is very likely that the difference in somatotype could have played a role in the difference in maximal speed and COD ability in addition to the neuromuscular factors articulated previously. In this regard, reduced endomorphy was the best predictor of all the performance measures in boys, especially for the 20 m sprint time and COD task. These findings are similar to those of Legaz and Eston [295] who reported that a reduction of adipose tissue consistently led to faster sprints in adults. However, the predictive model of the girls' 20 m sprinting performance differed from the boys with increased body mass being the best predictor (18%). Peak weight velocity occurs about 6-9 months post PHV and coincides with peak strength velocity [52]. As the girls sample spread from Pre-PHV to Post-PHV, peak weight velocity might have been reached for some of them and may explain the shared variance between body mass and sprinting performance. In this sense, Martin et al. [4] also demonstrated that in 7-17 year old females, peak power was most likely to be determined by the quantitative properties of the muscle (i.e. lean leg volume, mass, R^2 = 68%). The influence of body mass and associated maturity status on explosive performance in girls was also supported in this study by the significant relationship between sprint times and PHV offset and the best predictive ability of jump length performance with PHV offset.

For youth male soccer players around and past PHV (13-15 years old), mass and maturity also accounted for 50% of the variance in 30 m sprint and height and maturity status accounted for 41% of vertical jump performance, while age was not entered in the model [96]. However, PHV offset of the current male sample was not a significant predictor of performance apart from COD time, probably because the boys had not reached PHV, and the associated physiological changes (e.g. hormonal rise) likely to influence explosive action [296]. Age, on the other hand, added to the predictive model in all performance measures in boys apart from jump height. It is therefore likely that until PHV is reached, chronological age is a better determinant of explosive performance than maturity status considering the greater time available for motor learning. In support of this

argument, age but also hours of training were significantly correlated to the COD time in both sexes. Given the locomotor complexity of COD tasks [297], it can be argued that greater skills and motor learning are required in these tasks as compared to sprinting or jumping and therefore more sensitive to age and hours of training.

Practical Applications

There are a number of original findings that have important implications to the assessment and training practice of youth populations. First, a common sex scaling factor to account for body mass in horizontal and vertical power can be used in athletes aged 9-12 years old. Practitioners should aim to determine their test and sample specific body mass scaling factor rather than using theoretical models based on the assumption of body dimension similarity (b = 0.67). Second, youth coaches need to be aware that the sex-related differences in explosive performance are specific to neuromuscular requirement of the tests and influenced by maturity. Prior to male PHV, both sexes may compete on even ground in activities requiring jump power (e.g. volleyball), but boys are likely to excel more than girls from a young age in sports or events where maximal speed and COD play a large role (e.g. soccer, 60 m dash). Third, gender specific training may also be necessary given the early onset of PHV in girls. A training emphasis on strength gain and forceful explosive actions can occur sooner in girls (>12 years old) than boys (>14 years old). Given the smaller window due to early maturation and apparent reduced natural ability for maximal speed and COD, a training emphasis of these tasks should occur earlier in girls. Finally, age, maturity, somatotype and body mass should be taken into account when interpreting explosive performance of young athletes and part of a monitoring system in development programs. However, the practitioner must be mindful that these predictors are gender specific and may change with growth and maturation.

Chapter 7: Adjustment of measures of strength and power in youth male athletes differing in body mass and maturation

Prelude

As discussed in the previous chapters, adjustment for body mass and maturation of force, power and velocity measures for youth athletes is important for talent identification and development purposes. Considering the gender differences in force, power and velocity from the onset of puberty, it is necessary to exclude this confounding effect and concentrate on one gender when investigating the effect of growth and maturity on these characteristics. Both quantitative and qualitative factors seem to account for the development of strength, power and velocity capability in youth. Quantitative factors include increases in muscle mass, muscle cross-sectional area, and muscle fibre diameter, while qualitative factors include genetics, muscle metabolism, neural and hormonal influences. The qualitative and quantitative factors may act at different times or simultaneously during growth and maturation and create a change in the force-velocity-power profile throughout development. Scaling force, velocity and power variables for body mass may disentangle the quantitative from the qualitative factors responsible for the natural development of these characteristics. PHV occurs around the time of high specialisation in some sports (13-14 y) and is associated with a large number of morphological and physiological changes, so it would seem important to understand the change in the force-velocity-power profile of the youth athlete during this period of accelerated growth. Therefore, the purpose of this study was to use allometric scaling to disentangle the effect of body mass on the force-velocity-power profiles of maturing male athletes.

Introduction

In many team sports, muscle power is regarded as a defining physical attribute of elite players that needs to be trained progressively and monitored from an early stage of a player's development. Power output is the product of force and velocity and is defined and limited by the force-velocity relationship [269]. On this basis, maximal power output may improve by an increased ability to develop force at a given velocity and/or velocity at a given force [223, 298]. Several cross-sectional [15, 176, 182, 299] and longitudinal [4] studies using cycling ergometers have investigated the role of growth and maturation and associated quantitative changes (e.g., in body mass, lean leg volume) and qualitative changes (e.g., in inter-muscular coordination, motor unit recruitment) in muscle properties on the force-velocity-power relationship. However, the applicability of the findings to activities incorporating running and jumping is problematic, since cycling requires limited use of the posterior chain hip extensors and is not a weight-bearing exercise [9].

The vertical jump and its derivatives are some of the most widely used movements to assess the power of the leg musculature because of their simplicity. The jumps can also be considered as some of the most "explosive" tests, owing to both the short duration and the high intensity of the movement [223]. Researchers [18, 23, 230, 270] have investigated the force-velocity-power relationship using loaded jump squat protocols to quantify the effect of strength, competition level and training programs on this relationship. The force-velocity-power profile during ballistic jump movements has been shown to differentiate stronger from weaker athletes [18], level of play [230] and individual specific force-velocity relationships within a group of athletes [23]. Such an approach can also provide insight into the mechanistic changes responsible for power increase during growth and maturation [8]. An isoinertial loading protocol has also been used concurrently for maximal strength prediction and force-velocity-power profiling [24]. The benefits of such loading protocols are many, but no studies, to the authors' knowledge, have investigated the role of maturity status on the isoinertial force-velocity-power relationship, which may be more relevant to the on-field requirements of the youth athlete.

The force-velocity-power profile is affected by certain properties of skeletal muscles that change during growth and maturation. For example, increased muscle cross-sectional area with age is likely to influence the force component of power, while greater sarcomere length may enhance velocity capabilities [8]. Other factors such as motor-unit

recruitment may affect both aspects of the force-velocity relationship responsible for power output [200]. When comparing young athletes, controlling for body mass may provide an insight into the mechanisms responsible for the changes in force-velocity-power relationship during growth and maturation. Strength and power variables are commonly expressed using ratio scaling (e.g., power per unit of body mass) but such scaling often fails to produce a size-free index. Allometric scaling (e.g. power per unit of mass raised to some exponent) is commonly accepted as a better method to scale for body mass [35]. Specific theoretical scaling models for force, power or speed have been suggested [283], but to accurately account for body mass, exponents specific to the performance test and the athlete group should be applied [35]. Therefore, the purpose of this study was to use allometric scaling to investigate strength and power relationships in a ballistic loading test with a group of maturing male athletes.

Methods

Subjects

Seventy-four males between 11 and 15 years of age volunteered for this study. All participants were nominated by their physical education teacher to be part of a school sports academy. Participant characteristics are presented in Table 7.1. The Human Research Ethics Committee of AUT University approved the study and both the participants and their parents/guardians gave their written consent/assent prior to the start of the study.

Testing procedures

Participants attended one designated testing session preceded by a familiarisation session of all testing procedures. Anthropometric measurements were taken before performance testing. The standing height (cm), sitting height (cm) and weight (kg) were measured and the body mass index (BMI) calculated. The maturity status of the athletes determined using years from peak height velocity (PHV offset) [137] as well as the percentage of predicted adult stature [141]. After determination of maturity status, athletes were split into three maturity groups for analysis (see Table 7.1).

Table 7.1. Subject characteristics (mean ± SD) of the maturity groups based on peak height velocity (PHV)

Variables	Pre PHV (N = 29)	Mid PHV (N =28)	Post PHV (N = 16)
Age (y)	12.1 ± 0.7	13.4 ± 0.6	14.4 ± 0.4
PHV offset (y)	-1.7 ± 0.5	-0.2 ± 0.5	1.0 ± 0.4
Height (cm)	152 ± 6	166 ± 8	173 ± 4
Relative height (%)[a]	85.4 ± 2.4	91.7 ± 2.2	96.2 ± 1.7
Mass (kg)	40.7 ± 4.7	54.6 ± 8.7	63.1 ± 9.6
Leg length (cm)	74.2 ± 3.8	80.1 ± 5.2	82.2 ± 2.6
Body mass index (kg.m^{-2})	17.4 ± 1.6	19.8 ± 2.6	21.1 ± 2.9

All differences between groups were clear.
[a]Height as a percent of predicted adult height.

Subjects then undertook a 15-minute standardized warm-up using the different loads employed in the testing. Performance testing consisted of three trials of ballistic concentric squats on a supine squat machine (Fitness Works, Auckland, New Zealand) at five different relative loads to body mass (%) in a randomised order: 80%, 100%, 120%, 140% and 160%. The mean of the three trials was used for further analysis. Prior to each load, participants were asked to fully extend their leg to determine the zero position, which was used to determine the end of the pushing phase. A recovery of 30 seconds between trials within load and 120 seconds between loads was given. The foot position and knee angle (70°) were controlled for each trial [22]. The supine squat machine was designed to allow novice participants to perform maximal squats or explosive squat jumps, with the back rigidly supported, thus minimizing the risk associated with such exercises in an upright position (e.g. excessive landing forces, lumbar spine flexion and extension) (Figure 7.1).

A linear position transducer (Celesco, Model PT9510-0150-112-1310, USA) attached to the weight stack measured vertical displacement relative to the ground with an accuracy of 0.1 cm. These data were sampled at 1000 Hz by a computer based data acquisition and analysis program. The displacement-time data were filtered using a low-pass 4th-order Butterworth filter with a cut-off frequency of 50 Hz, to obtain position. The filtered position data were then differentiated using the finite-difference technique to determine velocity (v) and acceleration (a) data, which were each successively, filtered using a low-pass 4th-order Butterworth filter with a cut-off frequency of 6 Hz [273]. The force (F) produced during the thrust was determined by adding the weight of the weight stack to the force required to accelerate the system mass, which consisted of the mass of the

weight stack (mWS), the mass of the participant (mP), and the mass of the sled (mS), so F = g(mWS) + a(mWS + mP + mS), where g is the acceleration due to gravity and a is the acceleration generated by the movement of the participant. Following these calculations, power was determined by multiplying the force by velocity at each time point. Mean force, velocity and power were determined from the means of the instantaneous values over the entire push-off phase (until full leg extension, i.e. position 0). The external validity of the derived measurements from a linear position transducer have been assessed using the force plate as a "gold standard" device (r = 0.81-0.96) [259, 260, 275], with the only major limitation of underestimating force and power output [260].
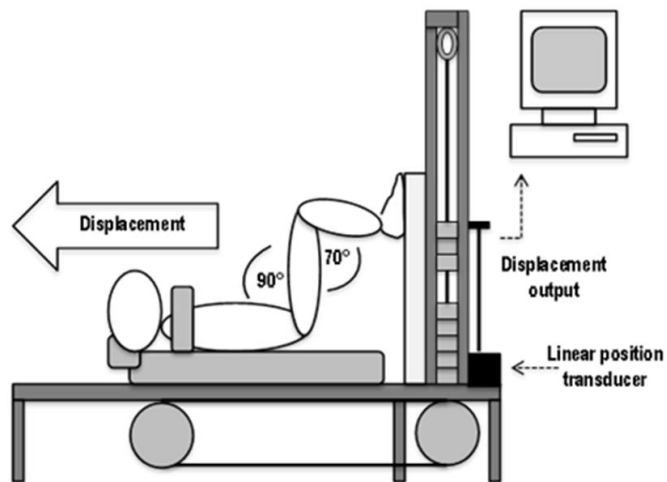
Figure 7.1. Experimental set up on the supine squat machine.
The linear position transducer was attached the weight stack to provide displacement data output as the participant moved horizontally.

Data analysis

Concentric leg-press squat one-repetition maximum (1RM) was estimated via the load-velocity relationship [24]. The 1RM velocity was not calculated in the current study and this value (0.23 m.s^{-1}) was extracted from previous studies in adults [24, 273] to be plotted on the load-velocity curve to extract 1RM. A pilot study on 10 children involved in the current study found a Pearson correlation of 0.94 (90% confidence limits 0.80 to 0.98) between the actual 1RM (118.5 ± 27.3 kg) and predicted 1RM (112.1 ± 23.0 kg) using a 1RM velocity of 0.23 m.s^{-1}. Force-velocity (F-v) relationships were determined by least-

squares linear regressions using mean force and velocity at each load. Individual force-velocity slopes were extrapolated to obtain Fmax and Vmax, which corresponded to the intercepts of the F-v slope with the force and velocity axes respectively [23, 270]. Since the power-load relationship is derived from the product of force and velocity, it was described by second-degree polynomial functions and maximal power output (Pmax) and the optimal load at which Pmax occurred was determined using the power-load regression curve [273]. The goodness-of-fit of the individuals' quadratics was expressed as a correlation coefficient calculated by taking the square root of the fraction of the variance explained by the model, after adjusting for degrees of freedom; the values were then averaged. This method has been validated against vertical jump height in a previous study (r = 0.67) (38) as well as against vertical peak power produced in a countermovement jump (0.89; 90% confidence limits 0.83 to 0.94) and 10-m sprint time (-0.79; -0.61 to -0.81) in the current population sample (unpublished observations).

Statistical Analysis

Data in the text and figures are presented as means ± standard deviations (SD). Initially, pairwise comparisons of performance variables between groups were conducted without taking body mass into account using with a customised published spreadsheet [300]. Differences in means between groups were expressed in percent units derived via log transformation. Magnitudes of differences were assessed by standardization of the log-transformed performance measure: dividing the difference in means by an SD. The appropriate SD was the square root of the mean of the variances of performance in the two groups of interest.   The effect of body mass on each performance variable was then investigated using an allometric scaling model y = $a.x^{b,}$ where y is the performance variable, x is body mass, *a* is a constant and *b* is the allometric scaling factor. The model was linearized by taking natural logarithms of both sides: ln(y) = ln(*a*) + *b*.ln(x), allowing estimation of *b* as a slope in a linear regression. Initially, separate linear regressions were performed for each maturity group. The difference in slope between groups was evaluated by expressing each slope as the effect of two SD of ln (body mass), then comparing these effects between pairs of maturity groups by standardization. The appropriate SD were now the standard errors of the estimate (SEE) from each regression (because the SEE represents typical differences between subjects after adjustment of performance to the same body

136

mass). As the differences in scaling factors between groups for a given performance measure were mostly trivial but unclear, a multiple regression model was devised to provide a single scaling factor and a single SEE for each measure using the Linest function in Excel. The model consisted of ln(body mass) as a simple numeric predictor, an intercept representing the allometric constant $\ln(a)$ for a reference PHV group, and two dummy variables each coded as 0 or 1 to represent data coming from each of the other two PHV groups. Several such analyses were performed to obtain the pairwise comparisons of the $\ln(a)$, representing mean difference between PHV groups after adjustment for body mass. The standard error provided by Linest for the coefficient of the dummy variable was used to calculate 90% confidence limits for the group differences. Magnitude of differences in mean performance between maturity groups was evaluated via standardization within the allometric analysis using the SEE from the multiple regression model.

Threshold values for assessing magnitudes of standardized effects were 0.20, 0.60, 1.2 and 2.0 for small, moderate, large and very large respectively [186]. Uncertainty in each effect was expressed as 90% confidence limits and as probabilities that the true effect was substantially positive and negative. These probabilities were used to make a qualitative probabilistic mechanistic inference about the true effect [186]: if the probability of the effect being either substantially positive or substantially negative was <5% (very unlikely), the effect was deemed clear and reported as the magnitude of the observed value, with the qualitative probability that the true value was at least of this magnitude. The scale for interpreting the probabilities was as follows: 25–74%, possible; 75–94%, likely; 95-99.5%, very likely; >99.5%, most likely [186]. The effect was otherwise deemed unclear, because the span of its 90% confidence interval (CL) was consistent with a true effect that could be substantially positive and negative. Use of a 90% CL allows for decisive outcomes with sample sizes that are one-third those for outcomes based on null-hypothesis testing with 80% power for 5% significance [186].

Results

Subject characteristics for the three maturity groups are presented in Table 7.1. The differences between groups for age and maturity (PHV offset and predicted adult height) were large to extremely large, while the differences in height, mass and leg length were at least small.

Before adjustment for body mass, the differences in 1RM, Pmax and Fmax between Pre PHV and other maturity groups ranged from large to very large, while the differences between Mid and Post PHV were moderate to large (Table 7.2). The difference in Vmax was unclear between Pre and Mid PHV but large between these two groups and Post PHV, which in turn influenced differences in the F-v profile: the Pre PHV group was more velocity dominant and the Mid PHV group more force dominant compared with the Post PHV group. Optimal load for Pmax derived from the power-load quadratic curve (goodness-of-fit: $R^2 = 0.79$; SEE = 20.7 W) expressed as percent of body mass for Pre, Mid and Post PHV groups were respectively 93 ± 14, 93 ± 18 and 90 ± 14 (mean ± SD).

Table 7.2. Force, power and velocity characteristics (mean ± SD) of the maturity groups based on peak height velocity (PHV)

Variables	Pre PHV (n = 29)	Mid PHV (n = 28)	Post PHV (n = 16)	Difference between groups (%), with 90% confidence limits		
				Mid-Pre PHV	Post-Mid PHV	Post-Pre PHV
1RM (kg)	77 ± 12	107 ± 20	126 ± 18	39 (28, 50) large***	18 (9, 29) moderate**	64 (52, 77) very large****
Pmax (W)	275 ± 65	400 ± 101	567 ± 102	44 (30, 61) large**	44 (21, 61) large**	108 (88, 131) very large****
Fmax (N)	770 ± 120	1090 ± 200	1220 ± 170	40 (29, 51) large***	13 (3, 23) moderate*	57 (45, 70) very large****
Vmax (m.s^{-1})	1.42 ± 0.29	1.43 ± 0.23	1.98 ± 0.43	1 (-7, 10) unclear	37 (22, 53) Large**	38 (23, 55) Large**
Fmax/Vmax	-570 ± 130	-780 ± 180	-660 ± 230	-38 (-54, 24) large*	18 (4, 29) moderate*	-14 (-33, 3) small**

*possibly; **likely; ***very likely; ****most likely
1RM = estimated one repetition maximum weight; Pmax = maximal power along the load spectrum; Fmax = estimated maximal force from force-velocity relationship; Vmax = maximal velocity from force-velocity relationship; Fmax/Vmax = ratio between Fmax and Vmax

Figure 7.2 shows an example of the allometric relationship between a performance measure (Pmax) and body mass with each maturity group having a separate slope. Table 7.3 shows the results of allometric analyses for each performance variable with a single slope fitted to the three maturity groups. After adjustment for body mass, Mid-PHV athletes had mostly moderate differences from Pre-PHV athletes. The differences in performance between Mid PHV and Post PHV were moderate to large in velocity-dependent variables (Pmax, Fmax/Vmax slope, Vmax) but remained small to unclear in force-dependent variables (1RM, Fmax). Finally, differences between Pre- and Post-PHV groups was moderate to large for all variables except for the Fmax/Vmax slope (Figure 7.3), where the difference was unclear.
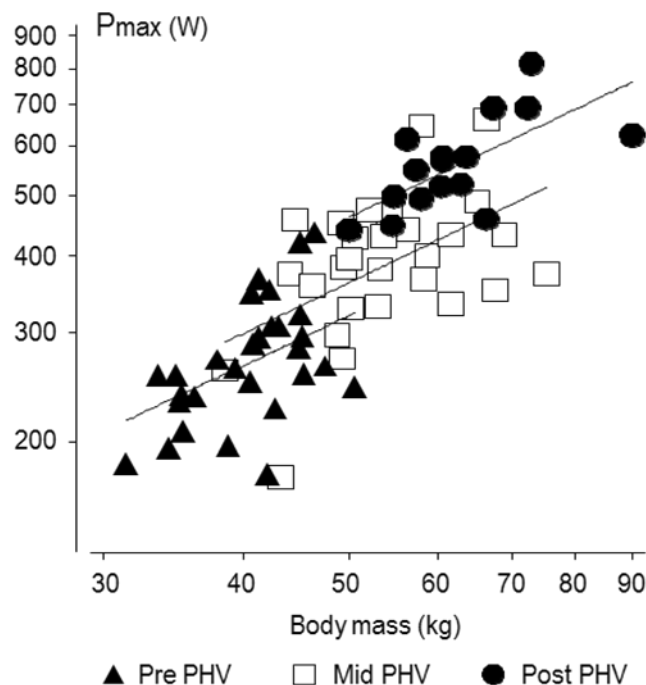
Figure 7.2. Maximal power (Pmax) and body mass relationship of the different maturity groups based on peak height velocity (PHV).
The lines shown are the least-squares regression lines provided by separate allometric analyses for each group. Axes are logarithmic to show the modeled relationships as lines rather than curves.

Table 7.3. Differences in mean performance between maturity groups after adjustment for body mass in an allometric analysis with a single scaling factor in the three groups.

Performance	Scaling factor (%/%)	SEE[1] (%)	Difference (%) in performance adjusted for body mass		
			Mid-Pre PHV	Post-Mid PHV	Post-Pre PHV
1RM	0.69 (0.49, 0.89)	14 (12, 16)	13 (4, 24) moderate**	7 (-1, 16) small**	21 (8, 31) large*
Pmax	0.85 (0.57, 1.14)	20 (18, 24)	13 (0, 28) small**	27 (14, 43) large*	44 (23, 69) large**
Fmax	0.56 (0.35, 0.77)	15 (13, 17)	19 (8, 30) moderate**	4 (-5, 13) unclear	23 (9, 39) large*
Vmax	0.42 (0.16, 0.68)	18 (16, 21)	-11 (-20, 0) moderate*	29 (16, 43) large*	15 (-1, 34) moderate*
Fmax/Vmax	0.14 (-0.23, 0.52)	26 (23, 31)	-33 (-55, -13) moderate**	19 (30, 7) moderate**	-7 (-32, 14) unclear

[1]The standard error of the estimate (SEE) is the within-group between-athlete standard deviation in performance used to assess the magnitude of the differences.
All data in parentheses are 90% confidence limits
*possibly; **likely; ***very likely; ****most likely
PHV = peak height velocity; 1RM = estimated one repetition maximal; Pmax = maximal power along the load spectrum; Fmax = estimated maximal force from force-velocity relationship; Vmax = maximal velocity from force-velocity relationship; Fmax/Vmax = ratio between Fmax and Vmax.
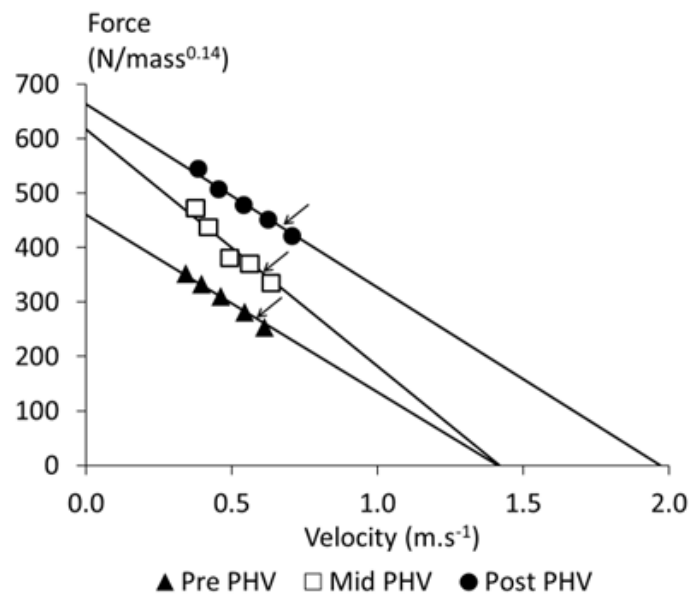
Figure 7.3. Force-velocity relationship across the load spectrum for Pre, Mid and Post peak height velocity (PHV) groups.
The intercepts on the Y and X axes represent maximal force and maximal velocity capabilities, respectively, estimated from the force-velocity relationship across the five loads. The arrow indicates where maximal power occurred on the load spectrum for each maturity group.

Discussion

The large differences in maturity status and age between the groups were reflected in somatic growth differences. PHV is usually preceded by an accelerated increase in leg length and followed by an increase in trunk velocity growth and peak weight velocity (0.5 to 1 y post PHV). [52]. Further, children passing through the age of peak weight velocity experience a change in the height-to-mass ratio represented by an increase in BMI [52]. The current study demonstrated a regular increase in BMI with maturity as well as a reduced difference in leg length once PHV was passed. These findings provide confidence that the groups were representative of the normal growth and maturation associated with human development.

The large increase in strength and power from the onset of PHV found in the current study could be attributed partly to the increase in body mass and associated change in muscle cross-sectional area during growth and its direct relationship with force [25]. To determine the role of maturation on strength, power and velocity capabilities independently of body mass, the dependent variables were allometrically scaled for body mass. A trivial and unclear difference in scaling factors for a given variable between the groups was found and a single scaling factor was calculated to compare athletes of different maturity status. The body mass scaling factor for 1RM, Fmax and Pmax (i.e., the b exponent) varied between 0.56 and 0.85. These mean results were dissimilar to the standard ratio usually used ($b = 1$) and only the exponent for 1RM ($b = 0.69$) fell near the theoretical value of 0.67 proposed by Jaric et al [283]. The value of 0.85 for Pmax was similar to that in previous research investigating allometric scaling of power output for body mass during countermovement jump ($b = 0.90$) [263], cycling in adults ($b = 0.92$) [37] and children ($b = 0.84$ to 0.97) [15] while the theoretical value of 0.67 still fell within the 90% CL of the analysis. The CL of the Vmax scaling factor across the three groups did not reach the zero value suggested elsewhere [283] (Table 7.3). Further, previous studies (32) have used the ratio standard ($b = 1$) to scale the F-v profile while this value approached zero in the current study. In summary, theoretical allometric scaling can be used with reasonable confidence in strength and power measures while velocity and F-v profile scaling still need further investigation.

Although there were clear differences in performance between groups after adjustment for maturity, the width of the confidence intervals for the differences and for the

associated scaling factors represent considerable uncertainty. More data should be acquired to reduce the uncertainty before the differences and the scaling factor for body mass are used in practical settings. Adjustment of an athlete's performance score to a given body mass within a maturity group (e.g., to the mean) would then be achieved by multiplying the score by (mean mass/athlete's mass)^{b}. To compare this athlete with those in another maturity group with, for example, 13% higher scores (Mid-Pre for 1RM in Table 7.3, the value specific to this athlete population), the mean mass in this formula would be that of the older group, and the resulting score would be multiplied by 1.13. This formula could be incorporated into a spreadsheet to allow practical assessment of athletes in the original units of the performance test. This approach would enhance talent identification processes and reduce the risk of selecting bigger and more mature athletes on the basis of greater absolute scores on a given test.

The remaining difference in performance between the maturity groups after adjustment for body mass was most likely associated with maturation-related changes in qualitative neuromuscular factors. Increases in strength and power could be due to greater percentage of motor unit activation, development of type II fibers, increased fascicle length and improved motor coordination [8, 25, 200]. Selective hypertrophy of Type II fibers [301] may be influenced by the increase in testosterone [302], which begins approximately one year before PHV [303]. The surge in testosterone could partly explain the moderate divergence of relative strength between boys at Pre PHV and Mid PHV observed in the current study (Table 7.3). In the current study, quantitative and qualitative changes of the neuromuscular system during growth and maturation appeared to explain the increase in muscle strength, but qualitative changes seem to play a greater role in explaining the differences from Pre to Mid PHV.

The relationship between strength and power dictates that an individual cannot possess a high level of power without first being relatively strong. This assertion is supported by the robust relationship that exists between maximal strength and maximal power production [223]. The concurrent large changes in relative strength (1RM and Fmax) and power (Pmax) from Pre to Post PHV support this contention. However, the difference in Pmax between Mid PHV and Post PHV was not associated with a change in strength of similar magnitude (Table 7.3). The velocity dominant F-v profile of the Post PHV group compared to the Mid PHV group (Figure 7.3) could explain why their similar relative strength did not lead to a similar Pmax. As the optimal load for Pmax was early in the load

spectrum for all groups, it seems that the ability to produce force at fast velocity was a more important determinant of Pmax and advantageous to the velocity dominant profile of Post PHV. It can be concluded that the shift in the F-v relationship at Mid PHV was associated with a reduced ability to produce high velocity contractions and optimally utilise maximal strength for Pmax. During the growth spurt around PHV, a disturbance of motor coordination explained by the differential timing of growth in both leg and trunk length has been observed and referred to as "adolescent awkwardness" [135, 179]. A reduced ability of motor unit synchronisation and inter-muscular coordination during fast movement would compromise both Vmax and Pmax [222] and thereby could explain the reduced gain in both variables and shift in the F-v profile for the boys at Mid PHV.

Conclusion

A number of original findings in this study have important implications to assessment and training practice for youth populations. Previous specific theoretical scaling models of body mass for force, power or speed that assume geometric similarity across all youth population. Such approach can be used approximately with force, strength and power measures but would seem problematic in velocity measures, given the results of this study. The scaling factors need to be determined over a large sample size before they can be used confidently in practical settings or otherwise need to be calculated for every new sample. Practitioners should also not compare athletes of different maturity status with the assumption that adjustment for body mass accounts for all maturational effects on strength, power and velocity capabilities, because qualitative factors were also responsible for the difference in performance between groups.

The development of power was associated not only with a strength increase during maturation but also with a change in velocity capability, as expressed by the F-v relationship. Around PHV, there was a reduced ability to utilise the same relative percentage of maximal force at high velocity compared to the other two groups, which affected the development of power. From these findings it may be inferred that maturity-specific training programs should be considered. For example, to increase power and reduce the negative shift of the F-v relationship, training at the onset of PHV should concentrate on fast velocity movement and high rates of force development with movements that require a considerable level of muscle coordination. Future longitudinal

144

studies should investigate the maturity effect on the dose-response of training methods focussing on force versus velocity.

Finally, it needs to be acknowledged that athletic performance such as jumping, sprinting or change of direction are ultimately defined by the net impulse generated into the ground, often in a very short amount of time. When assessing the determinants of athletic performance in youth, future research may benefit from a force-time analysis in addition to or instead of the force-velocity approach adopted in this paper.

Chapter 8: The contribution of vertical strength and power to sprint performance in youth

Prelude

In the previous chapter, it was observed that strength and power characteristics of the youth athlete changed during growth and maturation. Though these measures provide an excellent diagnosis of neuromuscular capability, the practicality of these measures needs to be determined in the context of on-field performance. Great speed is one of the major physical characteristics required in team sports. Assessing the contribution of strength and power to running sprint performance in maturing athletes would help to understand the magnitude of transference of these neuromuscular qualities into a locomotive task such as sprinting. Furthermore this information would guide programming to better effect. The previous chapters and other studies have demonstrated the influence of maturity and age as well as anthropometric characteristics of body size and composition on sprinting, strength and power output. Hence, the contribution of strength and power to sprint performance must be determined independently of these confounding factors. Based on these premises, the purpose of this study was to examine sprint performance in relation to PHV offset and determine the importance of strength and power on the natural development of sprint ability while accounting for anthropometric characteristics using allometric modeling.

Introduction

For many sports, sprint running is a corner stone of athletic development due to its impact on performance. Previous studies have demonstrated that, outside of the linear increase in sprint running with age, two periods of accelerated development occur between the age of 5-9 years [304] and 12-15 years [6]. The first accelerated period has been associated with the myelination of the central nervous system, while the second has been attributed to the rise of hormone levels (testosterone and growth hormones) and subsequent changes in strength and power throughout puberty [166, 198]. The strong relationships between strength, power and speed in adults [227] would support the support the latter argument. However, whether the rapid rise in strength and power around puberty changes their relative contribution to sprint performance is still largely unexplored.

By the onset of peak height velocity (PHV) at 12-13 years of age in males, most youth athletes are involved in a structured environment where systematic training design is important to their physical development [5]. Recent meta-analyses [166, 305] have reviewed the most relevant training methods to improve sprint performance but have not reported the corresponding changes in strength or power. As sprint ability is dependent on a number of anthropometric, physiological and biomechanical factors [156], different aspects of sprint performance may be enhanced by various training programs. Understanding the importance of strength and power on speed development during growth and maturation may provide insight into the factors responsible for sprint performance and offer guidance for training design. Several studies have shown the influence of maturity and age [6, 179, 306] as well as anthropometric characteristics of body size and composition [124, 181] on sprinting, strength and power output. Hence, investigations are needed that control for anthropometric variables across maturation, in order to determine the contribution of strength and power to sprint performance that is independent of these confounding factors. Maximal strength and power output are commonly expressed as standard ratio of units per body mass, despite statistical limitations [35]. Allometric scaling techniques have been recommended to account appropriately for the influence of body size variables on power output in children and adolescents instead of the standard ratio [181]. Therefore the purpose of this study was to examine sprint performance in relation to PHV offset and determine the importance of strength and power on the natural development of sprint ability while accounting for anthropometric characteristics using allometric modeling.

Methods

Subjects

Sixty-six males between 11 and 15 years of age volunteered for this study. All children were nominated by their physical education teacher to be part of the school sport academy. Participant characteristics are presented in Table 8.1. Both the participants and their parents/guardians gave their written consent/assent prior to the start of the study. The Human Research Ethics Committee of AUT University approved the study, which was conducted in accordance with the ethical standards of the IJSM [307] and conformed to the declaration of Helsinki.

Testing procedures

Participants attended two designated testing session preceded by a familiarisation session of all testing procedures. Anthropometric measurements were taken before performance testing in the first testing session. The standing height (cm), sitting height (cm) and weight (kg) were measured and the body mass index (BMI) calculated. Skinfolds (mm) were measured at 2 sites: triceps and medial calf, using a skinfold Slim Guide caliper (nearest 0.5 mm) from which the percentage body fat was calculated [243]. The maturity status of the athletes was determined using years from PHV (i.e. PHV offset) [137] as well as the percentage of predicted adult stature [141]. After determination of maturity status, athletes were split into three maturity groups for analysis (Table 8.1). Given the error associated with the calculation of PHV offset ($\pm$0.5 y, 95% confidence limits) [137], the reader must be mindful that an athlete may have been assigned to the wrong group. However, the small standard deviation in the determination of maturation in each group, the additional assessment of maturity status using percentage of predicted adult stature and the difference in leg length, height and body mass data between the groups (Table 8.1), indicated that the measurement of athletes maturation were relatively homogeneous and accurate.

On day one, performance testing consisted of three trials of ballistic concentric squats on a supine squat machine (Fitness Works, Auckland, New Zealand) at five different relative loads to body mass (%BM) in a randomised order to estimate 1RM: 80%, 100%, 120%, 140% and 160%. The mean of the three trials was used for further analysis.

Participants started by undertaking a 15-minute standardized warm-up using the different loads. Prior to each load, participants were asked to fully extend their leg to determine the zero position, which was used to determine the end of the pushing phase. A recovery of 30 seconds between trials within load and 120 seconds between loads was given. The foot position and knee angle (70°) were standardised. The supine squat machine was designed to allow novice participants to perform maximal squats or explosive squat jumps, with the back rigidly supported, thus minimizing the risk associated with such exercises in an upright position (e.g. excessive landing forces, lumbar spine flexion and extension).

A linear position transducer (Celesco, Model PT9510-0150-112-1310, USA) attached to the weight stack of the supine squat machine measured vertical displacement of the stack relative to the ground with an accuracy of 0.1 cm. These data were sampled at 1000 Hz by a computer based data acquisition and analysis program. The displacement-time data were filtered using a low-pass 4th-order Butterworth filter with a cut-off frequency of 50 Hz, to obtain position. The filtered position data were then differentiated using the finite-difference technique and filtered using a low-pass 4th-order Butterworth Filter with a cut-off frequency of 6 Hz to determine velocity (v) [273]. Average velocity was determined by averaging every instantaneous value over the entire push-off phase (until full leg extension, i.e. position 0). One-repetition maximum (1RM) was estimated via the load-velocity relationship [24]. The 1RM velocity was not calculated in the current study and this value (0.23 m.s^{-1}) was taken from previous studies in adults [24, 273] and was plotted on the individual load-velocity curve to calculate 1RM. A pilot study on 10 children involved in the current study found a Pearson correlation of 0.94 (0.80 to 0.98 ninety percent confidence limits) between the actual 1RM (118.5 ± 27.3 kg) and predicted 1RM (112.1 ± 23.0 kg) using a 1RM velocity of 0.23 m.s^{-1}.

On the second day, participants performed three countermovement jump (CMJ) with their arms akimbo and three 20-m sprints. The mean of the three trials was used for further analysis. Vertical ground reaction force data were collected with a portable plate (AMTI, ACP, Watertown, MA) using a sampling rate of 400 Hz during the CMJ and peak vertical power was provided by the manufacturers software (AccuPower, Version 1.5, Athletic Republic, Fargo, ND). The 20-m sprint was conducted on a wooden indoor surface and measured with a timing light system consisting of a dual-beam modulated visible red-light system with polarizing filters (Swift Performance Equipment, Walcol, Australia).

Participants were asked to start in a still split stance with the preferred leg forward 30 cm behind the starting line.

Statistical analysis

Initially, pairwise comparisons of performance variables between maturity groups were conducted using a published customised spreadsheet [300], without taking anthropometric characteristics (body mass, leg length, body fat), strength and power into account. The Linest function in Microsoft Excel (Office 10 version) was then used to perform allometric multiple linear regression analyses, in which the log of sprint time was predicted by the log of 1RM strength or by the log of peak power. Body fat as percent of body mass and the logs of body mass and leg length were included as main-effect predictors in both analyses to adjust for differences in these characteristics between the athletes, and sprint time was adjusted to the mean (for all athletes) of the anthropometric variables to allow visualization of the effect of strength and power on sprint time in plots of individual values. In initial analyses separate slopes (scaling factors) and intercepts were estimated for the effect or strength or power in each PHV group. The differences in slope between groups was evaluated by expressing each slope as the effect of two SD of log of strength or power, then comparing these effects between pairs of maturity groups by standardization–dividing the difference between the pairs by a SD [186]. The appropriate SD for strength or power was the square root of the mean of the variances of the log of strength or power in the three maturity groups. The appropriate SD for standardization was the standard error of the estimate in the analysis (effectively the mean of the standard deviations of adjusted sprint time in the three maturity groups). As the differences in slopes between groups were mostly trivial but unclear, subsequent analyses allowed for a single slope, so that differences in the intercepts of the model between the PHV groups represented differences in means of the groups for athletes with the same strength or power and anthropometric characteristics. The model consisted of log of strength or power as a simple numeric predictor, an intercept for a reference PHV group, and two dummy variables, each coded as 0 or 1, to represent data coming from each of the other two PHV groups. Several such analyses were performed to obtain the pairwise comparisons of the mean difference between PHV groups after adjustment for anthropometric characteristics and strength or power. The standard error

provided by Linest for the coefficient of the dummy variable was used to calculate 90% confidence limits for the group differences. Magnitude of differences in mean performance between maturity groups was evaluated via standardization within the allometric analysis using the standard error of the estimate from the multiple regression model. Uncertainty in the difference between the slopes for strength and power was assessed by bootstrapping using 1500 bootstrap samples [186].

Threshold values for assessing magnitudes of standardised effects were 0.20, 0.60, 1.2, 2.0 and 4.0 for small, moderate, large, very large and extremely large effects respectively [186]. Uncertainty in each effect was expressed as 90% confidence limits and as probabilities that the true effect was substantially positive and negative. These probabilities were used to make a qualitative probabilistic mechanistic inference about the true effect[186]: if the probabilities of the effect being substantially positive and negative were both >5%, the effect was reported as unclear; the effect was otherwise clear and reported as the magnitude of the observed value, with the qualitative probability that the true value was at least of this magnitude. The scale for interpreting the probabilities was as follows: 25–75%, possible; 75–95%, likely; 95-99.5%, very likely; >99.5%, most likely [186].

Results

Subject characteristics for the three maturity groups are presented in Table 8.1. The differences for age and maturity index (PHV offset and predicted adult stature) were large to extremely large between all groups, while the difference in height, mass and leg length between Mid and Post PHV were small to moderate. There was small to large differences in BMI between groups but the differences in body fat were unclear between maturity groups.

Table 8.1. Age, maturity, anthropometric and performance characteristics (mean ± SD) for each maturity group and the differences in the means between groups in raw units (with 90% confidence limits).

	Pre PHV (n = 25)	Mid PHV (n =26)	Post PHV (n = 15)	Difference between groups		
				Mid-Pre PHV	Post-Mid PHV	Post-Pre PHV
Age (y)	12.2 ± 0.6	13.4 ± 0.6	14.4 ± 0.4	1.3 (1.0, 1.5) very large*	1.0 (0.7, 1.3) large***	2.3 (2.0, 2.6) very large****
PHV offset (y)[a]	-1.7 ± 0.5	-0.2 ± 0.4	1.0 ± 0.4	1.5 (1.3, 1.7) very large****	1.2 (0.9, 1.4) very large***	2.7 (2.5, 2.9) extremely large****
Relative height (%)[b]	85.3 ± 2.2	91.8 ± 2.1	96.4 ± 1.4	6.5 (5.4, 7.5) very large****	4.6 (3.7, 5.6) very large**	11 (10, 12) extremely large****
Body mass (kg)	40.9 ± 4.8	54.6 ± 9.0	63.3 ± 9.9	14 (10, 17) large***	8.7 (3.4, 14) moderate**	22 (18, 27) very large***
Height (cm)	154 ± 6	166 ± 8	172 ± 4	12 (9.2, 16) large***	6.4 (3.4, 9.4) moderate**	19 (16, 21) very large****
Leg length (cm)	74.7 ± 3.6	80.1 ± 5.1	81.9 ± 2.4	5.4 (3.3, 7.5) moderate***	1.8 (-0.2, 3.8) small**	7.2 (5.6, 8.8) very large**
BMI (kg.m^{-2})	17.3 ± 1.6	19.8 ± 2.7	21.3 ± 3.0	2.4 (1.4, 3.4) moderate***	1.4 (-0.2, 2.9) small**	4.0 (2.5, 5.4) large**
Body fat (%BM)	16.2 ± 5.6	15.2 ± 5.6	14.9 ± 5.1	-1.0 (-3.6, 1.6) unclear	-0.4 (-3.3, 2.6) Unclear	-1.3 (-4.3, 1.6) unclear

*possibly; **likely; ***very likely; ****most likely.
BMI, body mass index; %BM, percent of body mass.
[a]Age minus predicted age of peak height velocity (PHV).
[b]Height as a percent of predicted adult height.

Table 8.2. Performance characteristics (mean ± SD) for each maturity group and the percent differences in the means between groups (with 90% confidence limits)

	Pre PHV (n = 25)	Mid PHV (n =26)	Post PHV (n = 15)	Difference between groups (%)		
				Mid-Pre PHV	Post-Mid PHV	Post-Pre PHV
1RM strength (kg)	77 ± 13	108 ± 20	127 ± 18	40 (28, 52) large***	18 (8.1, 30) moderate**	65 (52, 80) very large****
Peak power (W)[a]	1570 ± 280	2450 ± 510	2910 ± 610	55 (42, 70) very large**	19 (3.3, 36) moderate*	84 (61, 111) very large***
20 m sprint time (s)	3.68 ± 0.20	3.47 ± 0.19	3.31 ± 0.12	-5.7 (-8.1, -3.3) moderate***	-4.6 (-6.9, -2.2) moderate**	-10 (-12, 7.9) very large**

*possibly; **likely; ***very likely; ****most likely.
1RM, one-repetition maximum.
[a]n = 25 and 11 for Mid and Post PHV groups.

Before adjustment for anthropometric variables, the standardised differences in performance for 1RM strength, peak power and sprint time between maturity groups were moderate (Mid to Post PHV) to very large (Pre to Mid and Post PHV) (Table 8.2). After adjustment for anthropometric characteristics, the slopes of the relationship between sprint time and 1RM strength were -0.17%/% (90% confidence limits -0.25, -0.09), -0.17%/% (-0.25, -0.09), and -0.12%/% (-0.25, -0.09) for Pre, Mid and Post PHV, respectively; the corresponding slopes between sprint time and peak power were -0.19%/% (-0.27, -0.12), -0.24%/% (-0.32, -0.16) and -0.20%/% (-0.30, -0.11) (illustrated in Figure 8.1). The differences between the slopes were mostly trivial to small but unclear. Subsequent analyses with the same slope in each PHV group are summarized in Table 8.3.
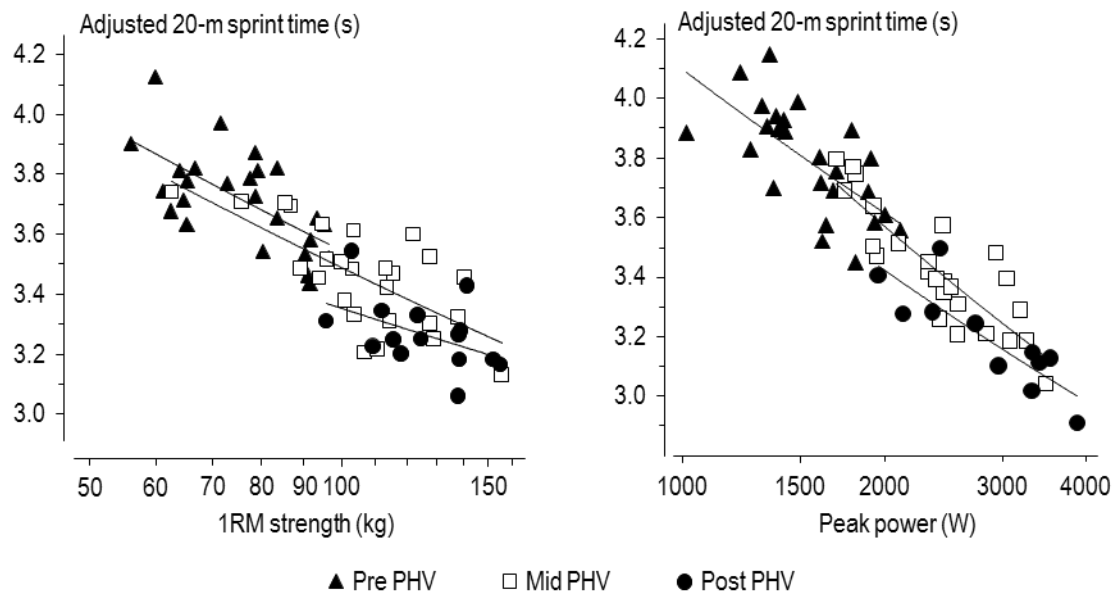
Figure 8.1. Relationships between 20 m sprint time (adjusted for body mass, leg length and percent body fat), 1RM strength (*left*) and peak power (*right*) in the three maturity groups based on peak height velocity (PHV). The lines shown are the least-squares regression lines provided by separate allometric analyses for each group. Axes are logarithmic to show the modeled relationships as lines rather than curves.

Table 8.3. Outcomes of allometric analyses[1] for prediction of sprint time from 1RM strength and peak power (with 90% confidence limits).

Predictor	Scaling factor (%/%)	SEE (%)	Difference in sprint time between groups (%)		
			Mid-Pre PHV	Post-Mid PHV	Post-Pre PHV
1RM strength	-0.16 (-0.22, -0.10)	3.8 (3.0, 4.1)	1.9 (-0.6, 4.5) small**	3.0 (0.8, 5.2) moderate**	5.0 (1.4, 8.6) large*
Peak power	-0.20 (-0.27, -0.14)	3.3 (2.8, 4.0)	0.9 (-1.5, 3.4) unclear	3.4 (1.1, 5.7) moderate**	4.3 (0.8, 8.0) large*

[1]For each predictor a single scaling factor was modeled in the three groups. The standard error of the estimate (SEE) is the within-group between-athlete standard deviation in performance used to assess the magnitude of the standardized differences between groups. The analyses included covariates to adjust for differences in leg length, body fat, and body mass between groups.
*possibly; **likely.
1RM, one-repetition maximum.

From the scaling factors, for 1RM strength and power in Table 8.3 it can be observed that a 10% difference in strength or power between athletes in a given PHV group would be associated with a 1.6% and 2.0% difference in sprint time, respectively. These scaling factors expressed as standardized effects of two SD of 1RM strength and power on speed were -1.64 (large) and -2.46 (very large), respectively; however, the moderate difference between the two outcome was unclear (0.82; -0.30, 1.94). It can be observed from Table 8.3 that most of the difference in mean sprint time between Pre and Mid PHV groups was accounted for by differences in strength and power, but there were still moderate to large differences in mean sprint time from Mid to Post and Pre to Post after strength and power were taken into account.

Discussion

The accelerated period of somatic growth created a large difference in height and body mass and moderate difference in leg length (Pre to Mid PHV). Once PHV was reached (Mid to Post PHV), these differences became moderate to small as additional gains in stature slow down and mostly depends on trunk growth (Table 8.1) [52]. In summary, the anthropometric characteristics of the maturity groups were representative of normal growth and maturation in human development of non-athletic children [52].

On average there were very large improvements in strength, power and sprint speed during the maturity window of two and half years. Previous researchers have reported similar differences between under-13/14 and under-15/16 soccer players in 20 to 30-m sprint performance (11%) [157, 306] and between 12 and 14 year olds in 20-m sprint

performance across various populations (10%) [308]. The current study is the first to report the development of isoinertial maximal strength and peak power during this growth period. Sprint performance differences changed linearly across the maturity groups (5-6%) while absolute maximal strength and power had a greater improvement from Pre to Mid PHV compared to Mid to Post PHV. Beunen et al. [179] have demonstrated an adolescent performance spurt in strength and power development to start about 1.5 years prior to PHV and to peak approximately 0.5-1.0 years after PHV. This large increase in strength and power has been attributed to the rise of circulating hormones at this maturational stage and subsequent physiological changes such as increased muscle mass, enzymatic activity and motor-unit activation [25, 175].

Anthropometric, strength and power characteristics had a greater effect on sprinting ability from Pre to Mid PHV compared to Mid to Post PHV. Once adjusted for anthropometric measurement, the standardized effect in sprint performance between Pre and Mid PHV was only small and unclear for a given strength and power, respectively (Table 8.3). This finding can be explained by accelerated increases in strength and power during this period [179], as well as the increase in leg length [52], muscle mass [296] and decrease in body fat [309] at the onset of PHV (Table 8.1). The difference in speed between Mid and Post PHV boys remained moderate once adjusted for strength and power, while the same comparison between Pre and Post PHV was still large. Several qualitative/neuromuscular factors can account for the change in sprint performance during growth and maturation, in particular improved motor coordination (i.e. running mechanics) via better intra-muscular coordination, greater synergistic contribution, and better co-activation of muscles [156, 198]. In this sense, Mendez-Villanueva et al. [306] also demonstrated that the difference in sprint performance between U14 and U16 soccer players was explained to a greater extend by qualitative factors associated with maturity status (i.e. PHV offset) in comparison to quantitative factors alone (i.e. body mass and fat free mass). During the growth spurt (i.e. Mid PHV), a disturbance of motor coordination explained by the differential timing of growth in both leg and trunk length has been observed and referred to as "adolescent awkwardness" [135, 179]. Reduced inter-muscular coordination during fast movements would compromise speed development [198] and thereby could explain the difference between Mid and Post PHV in sprint time even when adjusted for anthropometric, strength and power characteristics.

Although there were unclear differences between maturity groups in the slopes representing the effect of strength and power on sprint performance (Figure 8.1), the transference of strength and power to sprint performance was similar from Pre to Post PHV for the boys in the current sample. The slopes for strength and power were -0.16 and -0.20, theoretically meaning that a 10% change in strength and power would induce a 1.6% and 2.0% decrease in 20-m sprint time, respectively. To the authors' knowledge, no other studies have reported the %/% change of maximal strength and peak power to predicting sprint performance, but previous training data may give some insight into this relationship. For example, after 16 week of strength training [49] and 10 week of speed/plyometric training [190], 13-14 year-old soccer players improved their countermovement jump height (an indirect measure of leg power) by 12-13% and decreased their 10-30 m sprint time by 1-3%. A 10% improvement in strength or power as well as a 2% decrease in sprint time are therefore realistic in youth and seem interrelated. The fractional transference of strength and power gains to sprint performance could be attributed to the assessment of strength and power in a vertical plane in the current and previous studies [49, 190], while sprinting requires both horizontal and vertical force production [156, 310]. For future research, horizontal and vertical strength/power profiling may provide a better insight into the transference of these neuromuscular capabilities into sprint performance.

A comparison of the slopes of the relationships representing the effects of strength and power on speed addresses the question of whether power or strength is more beneficial to improve sprint ability in youth. The comparison of the standardised effects was unclear, but the observed moderate difference provides some evidence for the argument that increasing power rather than strength is more beneficial. Recent reviews of the training response in youth [166, 305] have supported the contention that complex and plyometric power training induce more improvement of sprint performance in youth compared with strength training, but further studies comparing training methods across maturity groups are required.

In conclusion, coaches must be mindful that athletes of the same age may differ considerably in maturity, which can affect physical performance and skew talent identification. Independently of strength, power and anthropometric characteristics, the maturity effect on sprint performance was greater from Mid to Post PHV compared to Pre to Mid PHV, suggesting that maturity dependant factors important for sprinting, such as running mechanics, may play a greater role during this period and should be emphasised in

training. Practitioners can expect that a training- or growth-induced improvement in vertical strength or power of 10% at any stage of maturation will produce a ~1.5-2% improvement on sprint performance in youth but need to keep in mind the prerequisite of movement competency before introducing explosive movement from a progression and injury-prevention perspective. Given that the difference in effect between strength and power on sprint performance could not be disentangled clearly, future research in athlete development should investigate the effect of strength versus power training on sprint performance and how maturity status may modify the training response.

Chapter 9: The effect of maturation on adaptations to strength training and detraining in 11- to 15- years olds

Prelude

The dose-response of a training stimulus as well as the decay in performance may be influenced by the natural development of athletic performance in maturing young athletes. Previously we found that the increase in force and power was greater from Mid to Post PHV compared to Pre to Mid PHV. According to the theory of windows of trainability, accelerated performance spurts (e.g. strength, speed) during growth and maturation should be utilised as training emphasis periods. Resistance strength training is often utilised as the first mode of neuromuscular training as it enables improved movement competency and basic strength levels, and does not require the high movement velocity and landing control which are characteristic of plyometric training. In terms of windows of trainability strength training would seem more beneficial for youth athletes post PHV, considering its emphasis on force rather than velocity. However, there is no empirical evidence to support the idea that performance spurts would be associated with greater training adaptations. Given these limitations, the purpose of this study was to determine the effect of movement-based strength training and detraining on force, velocity, power and sprint performance in young athletes of different maturity status.

Introduction

Knowledge of when to apply an optimal training stimulus during athlete development is essential for effective programming and improving athletic performance. Major morphological and neural changes are occurring due to growth and maturation [52]. These parameters could play an important role in the ability to adapt to a specific training stimulus. Based on these premises, the theory of windows of trainability associated with natural accelerated development of a specific athletic characteristic (e.g. speed) has been articulated [5, 6]. Several researchers [135, 179] have suggested an adolescent performance spurt in strength and power development about 1.5 years prior to peak height velocity (PHV) and peaking approximately 0.5-1.0 years after PHV, while an accelerated period in sprint performance was found to occur prior to PHV [135, 179]. However, there is a lack of empirical knowledge on the effects and optimization of training during growth and maturation, resulting in conjecture and debate [1, 204].

Resisted training methods are commonly used to improve strength, power and speed in young athletes [164]. A few studies [43, 45] have investigated the change in strength measures across different maturity groups after performing the same training program, but failed to determine the transference of strength gain to athletic performance or discuss any kinetic adaptations (force-velocity-power relationships). As maturation-related physiological changes (e.g. hormonal rise, central nervous system myelinisation) may favor different types of adaptation depending on maturity status, the assessment of strength, power, speed and the force-velocity relationship might provide greater insight into the way maturity modifies the effects of strength training. These physiological changes during growth may also influence the decay in performance following cessation of strength training. The maturity related difference in decay may guide maintenance programs and maturity-specific training periodization as well as disentangle training effect from natural athletic development. However, to the authors' knowledge, no studies have investigated the detraining effect of different maturity groups following the cessation of a strength training program.

Typically, volume and intensity parameters were described in previous studies but very little discussion has been given to exercise selection and progression in relation to athletic performance [164, 305]. Minimal attention to exercise selection may have contributed to the beneficial [49, 50] or trivial [41, 42, 51] enhancement of athletic

performance following strength training. Despite the unilateral and multi-planar force requirement in athletic performance, strength training design in youth mostly consisted in prescribing exercises bilateral and vertical in nature. The systematic implementation of additional unilateral and horizontal force production exercises would seem to be a more efficient approach to enhance athletic performance such as sprinting [207]. Recent literature in youth has also recommended implementing exercise progression based on movement competency with a strong coaching focus [2, 158]. Rather than using progressive overload training only, movement-based periodization could also be used as a loading parameter to stimulate strength adaptations and enhance athletic performance [311]. The strength, power and speed adaptations of such an approach to training youth of different maturity status have not been documented to the authors' knowledge. Given the limitations previously cited, the purpose of this study was to determine the effect of a movement-based strength training program and detraining on force, velocity and power measures as well as sprint performance in young athletes of different maturity status.

Methods

Subjects

Thirty-eight males between 11 and 15 years of age volunteered for this study. All participants were nominated by their physical education teacher to be part of the school sports academy. Following the baseline testing, four participants dropped out of the training program (90% retention) due to lack of interest (n = 2), non-training related injury (n = 1) and excessive sports commitments (n = 1) while one individual was sick on post training testing. Participant characteristics are present in Table 9.1. Following the detraining period four other participants did not complete the performance testing because of sports commitments. The Human Research Ethics Committee of AUT University approved the study and both the participants and their parents/guardians gave their written consent/assent prior to the start of the study.

Table 9.1. Baseline subject characteristics (mean ± SD) of the maturity groups based on peak height velocity (PHV)

	Pre PHV (N = 10)	Mid PHV (N = 11)	Post PHV (N = 12)
Age (y)	12.4 ± 0.7	13.6 ± 0.6	14.3 ± 0.7
PHV offset (y)	-1.7 ± 0.4	-0.2 ± 0.4	1.0 ± 0.4
Predicted adult height (%)	85.9 ± 2.9	91.8 ± 1.7	96.3 ± 1.7
Mass (kg)	41.5 ± 4.0	53.6 ± 10.0	66.0 ± 9.1
Height (cm)	152 ± 4.7	165 ± 5.8	174 ± 4.2
Leg length (cm)	74.3 ± 3.1	79.4 ± 4.1	82.7 ± 2.7
1RM (kg)	85 ± 12	107 ± 14	125 ± 10
Pmax (W)	336 ± 70	447 ± 97	570 ± 47
Fmax (N)	870 ± 130	1060 ± 140	1220 ± 120
Vmax (m.s^{-1})	1.53 ± 0.24	1.67 ± 0.36	1.97 ± 0.23
Fmax/Vmax (N/(m.s^{-1}))	-590 ± 140	-660 ± 160	-630 ± 120
Horizontal jump (cm)	136 ± 19	150 ± 23	156 ± 19
10 m sprint time (s)	2.13 ± 0.10	2.04 ± 0.14	1.96 ± 0.09
30 m sprint time (s)	5.31 ± 0.29	4.95 ± 0.27	4.73 ± 0.25

1RM = estimated one repetition maximal based on load-velocity relationship; Pmax = maximal power estimated from power-load relationship Fmax = estimated maximal force from force-velocity relationship; Vmax = maximal velocity from force-velocity relationship; Fmax/Vmax = ratio between Fmax and Vmax

Testing procedures

Participants attended two testing session at least 48 hours apart at baseline, post training and after detraining. The baseline session was preceded by an independent familiarisation session. Anthropometric measurements were taken prior to each of the testing occasions. Standing height (cm), sitting height (cm) and mass (kg) were measured and the athletes maturity status determined using years from/to PHV (i.e. PHV offset) [137] as well as the percentage of predicted adult stature [141]. Based on PHV offset, the participants, ranging from -2.36 to +2.05 years from/to PHV, were split into three maturity groups for analysis: Pre PHV (n = 10), Mid PHV (n = 11) and Post PHV (n = 12). Given the error associated with the calculation of PHV offset (±0.5 y, 95% confidence limits) [137], the reader must

be mindful that an athlete may have been assigned to the wrong group. However, the small standard deviation in the determination of maturation in each group, the additional assessment of maturity status using percentage of predicted adult stature and the difference in leg length, height and body mass data between the groups (Table 9.1), indicated that the measurement of athletes maturation were relatively homogeneous and accurate.

On day one, performance testing consisted of three trials of ballistic concentric squats on a supine squat machine (Fitness Works, Auckland, New Zealand) at five different relative loads to body mass (%BM) in a randomised order: 80%, 100%, 120%, 140% and 160%. The mean of the three trials was used for further analysis. Participants started by undertaking a 15-min standardized warm-up using the different loads. Prior to each load, participants were asked to fully extend their leg to determine the zero position, which was used to determine the end of the pushing phase. A recovery of 30 seconds between trials within load and 120 seconds between loads was given. The foot position and knee angle (70°) were standardised. The supine squat machine was designed to allow novice participants to perform maximal squats or explosive squat jumps, with the back rigidly supported, thus minimizing the risk associated with such exercises in an upright position (e.g. excessive landing forces, lumbar spine flexion and extension).

On the second day, participants performed three trials of horizontal jumps with their arms akimbo, followed by three 30-m sprints. The mean of the three trials was used for further analysis. Jump length was measured with a measuring tape from the starting line (toes just behind it) to the back of the heel on stick landing. The 30-m sprint was conducted on a wooden indoor surface and measured with a dual-beam timing light system (Swift Performance Equipment, Walcol Australia) placed at 0, 10 and 30 m. Participants were asked to start in a still split stance with the preferred leg forward 30 cm behind the starting line.

Data processing

To analyse the ballistic movement on the supine squat machine, a linear position transducer (Celesco, USA) attached to the weight stack of the supine squat machine measured vertical displacement relative to the ground with an accuracy of 0.1 cm, which corresponded to the horizontal displacement of the participant during the effort. Data was collected at a sample rate of a 1000 Hz by a computer based data acquisition and analysis program. The

162

displacement-time data were filtered using a low-pass 4th-order Butterworth filter with a cut-off frequency of 50 Hz, to obtain position. The filtered position data were then differentiated using the finite-difference technique to determine velocity (v) and acceleration (a) data, which were each successively filtered using a low-pass 4th-order Butterworth Filter with a cut-off frequency of 6 Hz [273]. The force (F) produced during the thrust was determined by adding the mass of the weight stack to the force required to accelerate the system mass, which consisted of the mass of the weight stack (M_{WS}), the mass of the participant (M_P), and the mass of the sled (M_S), so $F = g.M_{WS} + a(M_{WS} + M_P + M_S)$, where g is the acceleration due to gravity and a is the acceleration generated by the movement of the participant. Following these calculations, power (P) was determined by multiplying the force by velocity at each time point ($P = F \times v$). Average force, velocity and power were determined from the averages of the instantaneous values over the entire push-off phase until full leg extension. The external validity of the derived measurements from a linear position transducer has been assessed using the force plate as a gold standard device (correlations of 0.81-0.96), with the only limitation of underestimating force and power output [260].

The relationship between load and mean velocity was used to predict a dynamic one-repetition maximum (1-RM) at an average 1-RM velocity of 0.23 m•s^{-1} [24, 273]. A Pearson correlation of 0.94 between the actual 1-RM (119 ± 27 kg) and predicted 1-RM (112 ± 23 kg) was found in a pilot study with 10 of the current subjects. Using average force and velocity, force-velocity (F-v) relationships were determined by least-squares linear regressions. F-v slopes were extrapolated to obtain maximum force (Fmax) and maximal velocity (Vmax), which corresponded to the intercepts of the force-velocity (F-v) slope with the force and velocity axes respectively [23]. Since the power-load relationship is derived from the product of force and velocity, it was described by second-degree polynomial functions, maximal power output (Pmax) and the optimal load at which Pmax occurred determined using the power-load regression curve [273].

Training program

The training program consisted of two 45-min resistance training sessions per week for eight weeks with mean group adherence of 91% and a minimum individual requirement of 80% to be included in the study. It was followed by a 8-week detraining period. Prior to

each session, a 15-min warm-up focusing on fundamental movements such as lunging, squatting or good mornings as well as dynamic flexibility was conducted. The eight-week training was divided into two blocks of four weeks consisting of four main lifts and two core exercises. The main lifts were purposefully selected to develop both horizontal and vertical force production given the multi-planar nature of sprint performance. Also, to mimic the demands of running and sporting activities, two lifts were unilateral in each of the four-week cycles. Exercise progression was based on increasing load but also movement complexity across four different levels (bronze, silver, gold and platinum) in order to enhance movement competency, create a diverse training stimulus and challenge the athletes relative to their movement competency (Table 9.2). In the first session, all athletes started at the bronze level and self-determined their load with the coaches' help. Within the first session, the coaches assigned each athlete to the appropriate level of movement complexity based on pre-defined coaching points made clear to the athletes. Following the initial session, each athlete moved across the movement complexity when the coach decided that the previous level was completed with proficiency after an increase in mechanical load for 10-12 repetitions over two to three sessions. Three sets of 10-12 repetitions to near failure were conducted for each exercise apart from Sessions 1 and 9, when new exercises were being introduced (two sets). A rest of 90 s was allowed between sets. The coach to athlete ratio was $\leq 1:5$ and no more than 10 athletes trained at the same time to emphasise education and coaching. To increase motivation, athletes kept a diary to record number of sets and repetitions performed level of exercises and rating of perceived exertion (RPE), recorded on a visual analog scale (range 0-10) during the 8-week training period [312]. The session RPE indicated that training was lighter on weeks when new exercises were being introduced (Weeks 1 and 5) and increased progressively from 3.7 ± 1.3 (mean $\pm$ SD) to 6.1 ± 1.5 and from 5.5 ± 1.6 to 6.6 ± 1.3 for Blocks 1 and 2, respectively.

Table 9.2. Exercise progression during the two training blocks of 4 weeks.

	Exercise Level			
	Bronze	**Silver**	**Gold**	**Platinum**
Week 1-4				
Bulgarian split squat	Body mass	Front foot elevated	Dumbbells	Dumbbells front foot elevated
Lunge	Body mass in place	Body mass walking	Dumbbells walking	Dumbbells overhead walking
Hip thrust	Shoulder and feet on floor	Shoulder elevated	Single leg on floor	Single leg shoulder elevated
Single leg Romanian deadlift	Wall assisted	Body mass	Body mass hand reach	Dumbbells contralateral
Prone plank	Regular (60-90 s)	Alternate leg raise	Alternate leg raise hold	Alternate leg raise & abduction
Band hold	Straight hold	Rotation and hold	↑ band thickness	Partner disturbance
Week 5-8				
Step up lunge	Low box	High box	Dumbbells high box	Dumbbells high box overhead
Single leg squat	High box assisted	Low box assisted	High box unassisted	Low box unassisted
Hip thrust	Single leg floor	Single leg shoulder elevated	SL shoulder and feet elevated	Load single leg shoulder and feet elevated
Deadlift	Sandbag	↑load	↑load	↑load
Carpet slide hip flexion	Knee to chest	Single leg knee to chest	Toe to hand	Single leg toe to hand
Side plank	Foot on floor	Foot elevated	Foot elevated & abduction hold	Foot elevated & abduction

Uncertainty in the estimates of effects on performance was expressed as 90% confidence limits. Threshold values for assessing magnitudes of standardised effects (changes as a fraction or multiple of baseline standard deviation) were 0.20, 0.60, 1.2 and 2.0 for small, moderate, large and very large respectively [186]. These probabilities are not presented quantitatively but were used to make a qualitative probabilistic clinical inference about the effect in preference to a statistical inference based on a null-hypothesis test [186]. The effect was deemed unclear when the chance of benefit (a standardized improvement in performance of >0.20) was sufficiently high to warrant use of the intervention, but the risk of impairment was unacceptable. Such unclear effects were identified as those with an odds ratio of benefit to impairment of <66, a ratio that corresponds to an effect that is borderline possibly beneficial (25% chance of benefit) and borderline most unlikely detrimental (0.5% risk of harm). The effect was otherwise clear and reported as the magnitude of the observed value, with the qualitative probability that the true value was at least of this magnitude. The scale for interpreting the probabilities was as follows: 25–75%, possible; 75–95%, likely; 95-99.5%, very likely; >99.5%, most likely [186]. Magnitudes of differences in training effects between groups were evaluated non-clinically [186]: if the confidence interval overlapped thresholds for substantial positive and negative values, the effect was deemed unclear. The effect was otherwise clear and reported as the magnitude of the observed value with a qualitative probability, as above.

Results

The changes in body mass across all groups were trivial at eight and 16 weeks, apart from a small increase of 3.1% (90% confidence limits 1.1, 5.2) for Pre PHV after 16 weeks. In all groups, a small change in height of between 0.6 to 1.1% and 0.9 to 1.6% was found after eight and 16 weeks, respectively. There was a small increase in leg length in Pre (1.4%; 0.7, 2.2) and Mid (0.9%; 0.2, 1.6) relative to the Post PHV group (0.4%; -0.1, 0.9).

Relative changes and qualitative outcomes resulting from the within-group analysis are presented in Table 9.3 and illustrated in Figure 9.1. Comparisons of the changes in the three groups are presented in Table 9.4. The training effect on sprint performance, 1-RM, Pmax and horizontal jump was beneficial for all groups, but Mid and Post PHV improved

more than Pre PHV in sprint performance and Pmax to a small effect and Post PHV 1-RM improved more by a smaller effect compared to the other two groups. Kinetically, training only had a small positive effect on Fmax for the Post PHV group but a small to moderate effect on Vmax for all groups. The training program also induced a small shift in the F-v relationship towards velocity capabilities in Pre and Mid PHV and a moderate effect of maturity on the F-v relationship shift was observed between Pre and Post PHV.

A small detrimental detraining effect was found in 1-RM and sprint performances for Pre and Post PHV, as well as a small to moderate decay in Pmax for all groups. The detraining period was also associated with small decrease in Fmax in Pre and Mid PHV. There was a small increase in the decay in 1-RM and Pmax for Pre PHV compared to the other two groups as well as in Fmax compared to Post PHV. Reduction in sprint performance was only meaningful in Post PHV and there was a small enhancement in 10-m sprint time for the Mid-PHV group which led to the detraining period being less harmful for 10-m sprint time in the Mid PHV compared to Pre and Post PHV. All other comparisons following the detraining period were trivial or unclear, except for a small improvement in horizontal jump performance for the Post PHV group.

Table 9.3. Training and detraining effects[1] (with 90% confidence limits) for the performance and force-velocity variables for the three maturity groups based on peak height velocity (PHV).

	Training effect (post-training minus baseline) (%)			Detraining effect (detraining minus post-training) (%)		
	Pre PHV	Mid PHV	Post PHV	Pre PHV	Mid PHV	Post PHV
1-RM	3.6 (-1.0, 8.5) small↑*	3.5 (-0.1, 7.2) small↑＊	10.0 (6.7, 13.3) moderate↑***	-4.6 (-8.2, -0.8) small↓**	0.0 (-4.5, 4.7) trivial**	-0.7 (-3.8, 2.4) small↓*
Pmax	11 (7, 16) moderate↑*	16 (8, 24) moderate↑*	20 (14, 27) large↑**	-11 (-18, -3) moderate↓*	-3 (-11, 4) small↓*	-6 (-14, 2) moderate↓*
Fmax	-2.1 (-7.0, 3.0) small↓*	2.5 (-3.4, 8.7) unclear	8.7 (3.6, 14.1) moderate↑*	-6.6 (-14, 1.0) small↓**	-2.2 (-10.5, 6.9) small↓*	1.4 (-6.7, 4.2) small↑*
Vmax	16 (5, 29) moderate↑*	14 (2, 28) small↑**	11 (2, 22) small↑**	-2 (-19, 18) unclear	4 (-13, 24) unclear	-10 (-22, 5) small↓**
Fmax/Vmax	16 (3, 27) small**	10 (-6, 24) small*	2 (-11, 14) Unclear	5 (-24, 26) unclear	6 (-22, 27) unclear	-9 (-33, 11) unclear
Horizontal Jump	6.5 (1.2, 12.2) small↑**	6.8 (2.2, 11.6) small↑**	7.4 (4.7, 10.2) moderate↑*	2.4 (-4.1, 9.4) unclear	1.9 (-2.7, 6.6) unclear	3.7 (0.6, 6.8) small↑**
10-m sprint time	-2.6 (-4.0, -1.2) small↑***	-4.7 (-7.0, -2.3) moderate↑**	-4.0 (-5.7, -2.3) moderate↑**	0.1 (-1.2, 1.5) trivial**	-1.1 (-2.2, 0.1) small↑*	0.9 (0.0, 1.7) small↓*
30-m sprint time	-2.1 (-3.5, -0.7) small↑**	-3.6 (-5.0, -2.3) moderate↑**	-3.0 (-4.1, -2.0) moderate↑**	0.1 (-0.5, 0.6) trivial***	-0.4 (-1.6, 0.8) trivial**	0.6 (-0.5, 1.7) small↓*

[1]Effects are shown with probabilistic inferences about the true standardized magnitude

*possibly; **likely; ***very likely

↑ = improvement in performance; ↓ = impairment in performance; 1RM = estimated one repetition maximal based on load-velocity relationship; Pmax = maximal power estimated from power-load relationship; Fmax = estimated maximal force from force-velocity relationship; Vmax = maximal velocity from force-velocity relationship; Fmax/Vmax = ratio between Fmax and Vmax

Table 9.4 Differences between the three maturity groups (based on peak height velocity, PHV) in the training and detraining effects[1] (with 90% confidence limits) on performance and force-velocity variables.

	Training effect (post-training minus baseline) (%)			Detraining effect (detraining minus post-training) (%)		
	Mid – Pre PHV	Post – Mid PHV	Post – Pre PHV	Mid – Pre PHV	Post – Mid PHV	Post – Pre PHV
1-RM	-0.1 (-5.4, 5.5) unclear	6.2 (1.7, 11) small↑**	6.1 (0.7, 12) small↑*	8.0 (0.1, 17) small↑**	-0.7 (-5.9, 4.7) unclear	7.2 (-0.2, 15) small↑*
Pmax	4 (-4, 12) small↑*	4 (-4, 13) small↑*	8 (1, 15) small↑*	9 (-2, 21) small↑*	-3 (-13, 8) unclear	5 (-6, 18) small↑*
Fmax	5 (-3, 13) small↑*	6 (-1, 14) small↑**	11 (4, 19) small↑**	5 (-6, 17) unclear	1 (-9, 11) unclear	6 (-3, 16) small*
Vmax	-2 (-15, 13) unclear	-2 (-15, 12) unclear	-4 (-16, 9) unclear	6 (-16, 35) unclear	-13 (-31, 8.5) unclear	-7 (-26, 16) unclear
Fmax/Vmax	-7 (-31, 13) unclear	-9 (-32, 11) unclear	-16 (-39, 3.0) moderate*	1 (-38, 30) unclear	-16 (-58, 15) unclear	-14 (-55, 16) unclear
Horizontal jump	0.2 (-6.0, 6.9) unclear	-0.6 (-4.2, 5.6) unclear	0.8 (-4.7, 6.6) unclear	- 0.5 (-7.8, 7.3) unclear	1.8 (-3.4, 7.2) unclear	1.7 (-5.2, 9.1) unclear
10-m sprint	-2.1 (-4.7, 0.6) small↑*	0.7 (-2.1, 3.6) unclear	-1.4 (-3.5, 0.8) small↑*	-1.2 (-2.9, 0.5) small↑*	1.9 (0.5, 3.4) small↓**	0.7 (-0.8, 2.3) small↓*
30-m sprint	-1.6 (-3.4, 0.3) small↑*	0.6 (-1.0, 2.3) small↓*	-1.0 (-2.6, 0.7) small↑*	-0.6 (-1.8, 0.7) trivial**	0.6 (-1.0, 2.3) small↓*	0.4 (-0.7, 1.6) trivial**

[1]Effects are shown in percent units with 90% confidence limits and probabilistic inferences about the true standardized magnitude
↑ increase in training/detraining effect with maturation; ↓ decrease in training/detraining effect with maturation
*possibly; **likely
1RM = estimated one repetition maximal based on load-velocity relationship; Pmax = maximal power estimated from power-load relationship; Fmax = estimated maximal force from force-velocity relationship; Vmax = maximal velocity from force-velocity relationship; Fmax/Vmax = ratio between Fmax and Vmax
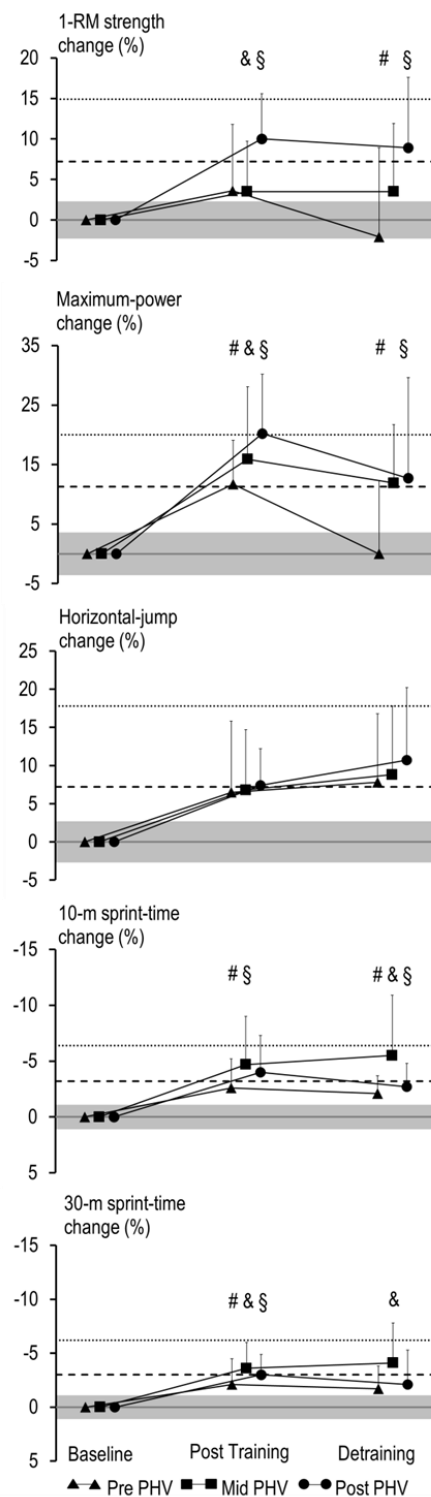
Figure 9.1. Changes in performance measures from baseline in the three maturity groups based on peak height velocity (PHV).

The shaded area represents trivial changes, the dash line represents the lower limit for moderate changes and the dotted line represents the lower limit for large changes (<0.20, >0.60 and >1.20 of baseline between-subject SD averaged over the three groups, respectively). Bars are standard deviations of changes from baseline to post training and baseline to detraining. #: small differences in training effect between Pre and Mid PHV groups; &: small differences in training effect between Mid and Post PHV groups; §: small differences in training effect between Pre and Post PHV groups; (1-RM: one repetition maximum).

170

Discussion

The current study demonstrated the efficiency of a new vertical and horizontal movement-based strength training approach to enhance force, velocity, power and speed measures in young athletes of different maturity status, with generally greater changes in Mid- and Post-PHV groups. In the detraining period the Pre-PHV group showed greatest loss of strength and power, the post-PHV group showed some loss of sprint performance, but all groups maintained or improved jump length. These results demonstrated that athletic performance may not only be induced by a training stimulus but also natural development, which is dependent on maturity status.

The training duration or the training stimulus did not induce any meaningful change in body mass for any of the groups. Peak mass velocity has been reported to occur about half a year to a year post PHV [52], but the program was probably of insufficient duration to elicit any measurable change. The greater change in height for Mid PHV compared to Post PHV over 16 weeks confirmed that the participants in this group were going through their growth spurt. Similarly, the greater increase in leg length over 16 weeks for Pre and Mid PHV compared to Post PHV was in line with normal somatic growth where peak leg length growth occurs just before PHV [137]. In summary, the anthropometric characteristics of the maturity groups seemed representative of the normal growth and maturation associated with human development [52].

The strength training program in the current study was beneficial in enhancing 1-RM, Pmax, 10-m and 30-m sprint time and horizontal jump in all maturity groups. To the authors' knowledge, the current study is the first to demonstrate the ability to enhance explosive actions in different planes of motion across different maturity groups. The small to moderate training effect on 10-m sprint time (-2.6% to -4.7%) and 30-m sprint time (-2.1% to -3.6%) was within the effect size (ES = 0.54) [164] and percent changes (-1.5% to -5.8%) [166] reported in meta-analyses. Previous strength training [313, 314] failed to induce a change in sprint performance despite an increase in strength and/or power. These findings are probably explained by the principle of training specificity, as these studies used exercises only in a vertical direction, whereas it seems wise to incorporate strategies to work the hips from a horizontal vector if increased speed and acceleration are sought [207, 315]. The hip-thrust exercise to stimulate end range hip extension strength, along with the other hip-extension exercises to stimulate flexed range hip extension strength such as the

forward lunge or deadlift, were found to be effective and appropriate to the age of the athletes in the current study. The effectiveness of these exercises was supported by their transference to produce a small to moderate increase in horizontal power (horizontal jump = 6.5% to 7.4%), which is comparable (5.7% to 7.3%) [42, 206, 313] or better (1.6% to 4.6%) [316, 317] than found in previous pediatric studies. Owing to the specificity of Pmax as an instantaneous power measure of less than 2 s, comparison to other studies is limited. If vertical jump height is considered as an indirect measure of vertical power [264], the moderate to large increase in Pmax in the current study was comparable to those of a meta-analysis reporting the effect sizes of resistance training on the vertical jump (ES = 0.99) [164]. While the training effect in the current study can be compared to other studies, the reader must recognize that the adaptations were sample specific and other subjects may have responded differently.

Even though the strength training program was beneficial for all maturity groups, the effects of training became greater with maturity in movements where vertical strength and power are dominant (1-RM, Fmax, Pmax, 10-m sprint), but not in high-velocity movement through multi-planar direction (30-m sprint and horizontal jump). A previous meta-analysis [165] also demonstrated that interpubertal and postpubertal subjects (Tanner stage 2-5) were more likely to increase strength levels after resistance training compared to prepubertal children (Tanner stage 1). Behringer et al. (2010) argued that the greater gain in strength with maturity was due to the hormonal rise during puberty. Interestingly, the magnitude of the change in strength (3.6% to 10%) was not as great as previously reported (14% to 32%) in studies with similar duration of training, frequency of training and age of subjects [42, 206]. The training background could explain this discrepancy as the current subjects were part of a sport academy while in the other studies [42, 206] the subjects were considered untrained. The training response may have differed in a different subject cohort. The minimal strength gain compared to other studies could also be attributed to intensity, which may not have been optimal for strength increase (10-12 repetitions vs 1-6 repetitions). However, the 10-12 repetition range was chosen as being most suitable for youth participants with limited resistance training history. The fact that the athletes' RPE were low in the initial sessions indicated that the loading could have been higher to induce greater training adaptations, but progressive loading was chosen to reduce initial muscle soreness and injury risk. Finally, the focus on exercise progression and unilateral movement

may have not allowed optimal loading the young athletes for strength gains but may have more benefit for long-term athletic development [2, 158].

A fundamental relationship exists between strength and power, which dictates that an individual cannot possess a high level of power without first being relatively strong. This assertion is supported by the robust relationship that exists between maximal strength and maximal power production [222]. The moderate increase in 1-RM for Post PHV associated with a large increase in Pmax would support this relationship. Yet, there was still a moderate training effect on Pmax for Pre and Mid PHV despite a possibly small increase only in maximal strength. As Pmax is the product of force and velocity and is limited by the F-v relationship, an increase in velocity capability can explain changes in power output as does an increase in force [222]. From the analysis of the F-v relationship, it was concluded that maturity groups had different kinetic adaptations to the strength training intervention. While the Post-PHV group increased their Fmax and Vmax, the training program resulted in greater increases in Vmax for the Pre and Mid PHV, as observed in differences in the F-v slope shift between Pre and Post PHV. Kinetic adaptations in the current study could have been partially independent of the training methods and related to the natural development of force, velocity and power during growth and maturation. Several researchers [135, 179] have demonstrated an adolescent performance spurt in strength and power development to start around 1.5 years prior to PHV and to peak approximately 0.5-1.0 years after PHV. In previous studies [4, 176], change in optimal velocity was found to be responsible for the natural increase in Pmax with age prior to puberty, whereas the increase of Pmax in pubertal and post-pubertal boys was accompanied by an increase in optimal force. In this sense, previous models of youth training have recommended training methods that stimulate inter-muscular coordination, movement efficiency and movement velocity prior to puberty [198] rather than strength training to improve power [166, 198].

Overall, the decay in performance was greater in high-force variables (1-RM, Fmax, Pmax) than in high-velocity variables (Vmax, sprinting). A recent review on the topic [318] also demonstrated that the effect of training cessation on maximal strength and power was quite similar during the first weeks. However there appeared to be a dissociation after 16 weeks of inactivity as maximal strength continued to decrease while maximal power remained leveled. An increase in the expression of fast muscle-myosin heavy-chain isoforms following a three months detraining period has been associated with an increase in

velocity capability which may have compensated for the loss in maximal force to maintain maximal power [319]. These adaptations could partly explain the initial decrease in maximal strength and power and maintenance in velocity capabilities in the current study. The Pre PHV boys underwent a greater detraining effect than the Mid and Post PHV groups in force dependent variable (1-RM, Fmax, Pmax) apart from Fmax between Pre and Mid PHV. The accelerated period in strength and power development during puberty [135, 179] may play a confounding role in adaptation and reduce the decay in strength during Mid and Post PHV (trivial to possibly small, respectively) in comparison to Pre PHV (possibly small) and adults (small to moderate) [184, 318] after the same period of training cessation. A previous review on strength maintenance in youth also supported a return to strength baseline in prepubescent after an eight-week detraining period [204]. The small decay in sprint performance for the Post PHV group could be associated with the small decrease in Vmax and an inability to maintain force at fast velocity following a detraining period. The maintenance of Vmax and sprint performance in Pre and Mid PHV but inability to maintain Fmax would suggest that a greater natural development of velocity capability could be observed during this period compared to force characteristics [4, 176], on the contrary to Post PHV. These adaptations could be related to the increase in fascicle length during somatic growth and faster maturation of the central nervous system prior to puberty [52].

The detraining phase enables to disseminate the possible contribution of natural development not only to maintain athletic performance after the cessation of training but also during the training phase. However, the lack of control group represented a limitation to the current study to disentangle with absolute clarity the contribution of natural development in performance enhancement following the training program. Based on the decay in performance following cessation of training, natural development could play a role in accelerated training adaptations in strength and power measures in Mid and Post PHV and velocity and sprint performance in Pre and Mid PHV but further research is this area should be conducted before conclusion can be made.

Perspectives

The strength training program was beneficial in improving vertical strength, vertical and horizontal power, 10-m sprint time and 30-m sprint time across different maturity groups, but the magnitude of training and detraining as well as the kinetic adaptations were maturity dependent. The maturity-specific force, velocity and power adaptations to training and detraining have important implications for the development of these neuromuscular characteristics during growth and maturation. Strength training was more beneficial at enhancing maximal strength, maximal power and sprinting in Mid and Post PHV groups than in the Pre PHV group. Some form of training other than (or additional to) strength training, such as activities providing a velocity stimulus, may be valuable for athletes Pre PHV [198], considering their lower response to strength training in the current study and greater natural velocity development in comparison to athletes who have entered PHV [4, 176]. Regardless, practitioners should include bilateral and unilateral vertical and horizontal force production exercises to optimally enhance all aspects of explosive athletic performance [207, 315]. Future research should attempt to compare the effects of velocity-dominant and force-dominant training in maturing athletes while accounting for the natural development in the measure of interest.

Chapter 10: Conclusions

Summary and discussion of main findings

Comprehensive models of long-term athlete development have been established, however, the integration of power as a key physical characteristic within these models has not been detailed. From the literature reviewed, several gaps in power assessment and training in youth were identified. The overarching question of this thesis was, therefore, to establish the role of human development and training interventions on the isoinertial force-velocity-power profile and maximal strength of youth. In regards to answering the methodological issues in power assessment, the determination of maturity status and allometric scaling were identified as key methodological considerations when investigating the development of power and were used throughout this thesis where appropriate. To further inform power training in youth, an evidence-based model for power development was established after a systematic review of the literature. Prior to PHV, a major focus on velocity of movement and fundamental movement patterns is necessary to exploit the natural development of velocity capability and develop good lifting technique. During PHV, a strong emphasis must be placed on force development via increasing loading/intensity and movement progressions, while maintaining an ability to produce high velocity movement and rate of power development. The years post PHV should be dedicated to power training with a concurrent emphasis on developing maximal force. Based on this literature review, the ensuing experimental chapters were designed to enhance the knowledge in this area and answer the specific aims outlined at the start of this thesis.

Many testing protocols (e.g. cycle ergometers, isokinetic machines) have been used to monitor power in youth, but for the most part the contraction modes were dissimilar to those utilized during athletic performance (i.e. isoinertial). Also, research investigating the components of power output, such as the force-velocity relationship and maximal strength was scarce. To monitor with confidence these variables, the variability associated with isoinertial assessment of the force-velocity-power profile and maximal strength in youth was investigated. The variability associated with maximal strength assessment and force-velocity-power profiling in youth, and whether maturity status was likely to influence the reliability of these measures were determined in Chapters 4 and 5. The effect of maturity

was 'likely' to 'very likely' to influence the variability of the eccentric variables but not so for any of the concentric variables. During a VCMJ and HCMJ, vertical concentric mean and peak power as well as jump height or distance were the most reliable measures (change in the mean - CM = -5.4% to 6.2%; coefficient of variation - CV = 2.1% to 9.4%; intraclass coefficient – ICC = 0.82 to 0.98), while vertical eccentric mean power was the only eccentric variable with acceptable reliability for both jumps (CM = -0.7% to 10.1%; CV = 5.2% to 15.6%; ICC = 0.74 to 0.97). When the reliability of the force-velocity-power profiling and estimated maximal strength in youth was quantified using a concentric ballistic leg press test at five randomised loads (80, 100, 120, 140, 160% body mass), all kinetic and kinematic variables were found reliable (CM = -1 to 14%; CV = 3-18%; ICC = 0.74-0.99). However, a familiarization session was found likely to be beneficial, especially at 160% and 80% body mass loads. Estimated maximal strength, force, velocity and power were also reliable after familiarization (CM = 2-14%; CV = 6-12%; ICC = 0.78-0.97) unlike maximal force/velocity ratio (CM =0-3%; CV = 23-25%; ICC = 0.35-0.54) and load at maximal power (CM = -1 to 2%; CV = 10-13%; ICC = 0.26-0.61). It was concluded that a great deal of movement variability was associated with the eccentric phase of CMJs, especially in Pre PHV during the HCMJ. Vertical concentric mean and peak power and eccentric mean power were deemed reliable and appropriate to be used in children as indicators of jump and stretch-shortening cycle performance, while the assessment of force-velocity-power and maximal strength can be conducted reliably, once a familiarization session across the load spectrum has been performed. This information guided assessment protocols for the ensuing studies and should assist practitioners in understanding those variables that can be assessed and monitored with consistency in the youth athlete.

Further, understanding the differences in strength, power, speed and agility measures between athletes of different gender and maturity status was thought to be a contributing factor to enhance understanding of long-term power development in youth. The sex-related differences in explosive actions during late childhood as well as the sex-specific anthropometric and maturity factors responsible in these actions had not previously been investigated. Allometric scaling of power for body mass and predictive anthropometric and maturity variables to power, speed and agility were investigated to determine the sex-related differences in explosive actions during late childhood. From allometric analysis it was concluded that a common sex scaling factor of body mass can be used for vertical ($b = 1.02$) and horizontal ($b = 0.97$) power. No significant sex difference in

relative acyclic leg power was found before and after controlling for maturity status. Gender differences in 10 m sprint, fly 10 m and change of direction in the agility track were only found significant once adjusted for maturity ($P < 0.05$). However, boys performed significantly better than girls in the 20 and 30 m sprint, and agility regardless of maturity status ($P <0.05$). Reduced endomorphy in boys was the best predictor of explosive actions ($R^2 = 7-22\%$), while female performance was best explained by mass and maturity status ($R^2 = 15-19\%$). From these it was thought important to monitor somatotype, age, maturity and body mass during the development of youth athletes, to better understand explosive performance. Furthermore, the use of generic allometric scaling factors as purported by some researchers was found inappropriate, the scaling factors found to be sample and variable specific. These findings further guided our methodological approach in the final chapters of this thesis.

From the literature reviewed it was observed that there was also limited knowledge as to the quantitative and qualitative neuromuscular factors accounting for the change in strength and force-velocity-power profile during growth and maturation. This limitation provided the primary focus for Chapter 7 where the importance of adjustment for body mass and maturation when assessing strength, power and velocity measures in talent identification and development was further investigated. Most differences in scaling factors between groups for a given performance measure were trivial but unclear, and a single scaling factor was estimated for each measure. Strength and power measures showed a greater dependency on body mass than velocity-related variables (scaling factors of 0.56 to 0.85 vs 0.42 to 0.14 %/%). There were large differences in mean performance between maturity groups, but even after adjustment for body mass most differences were substantial and small to large in magnitude (10% to 44%). Improvements in strength and power with maturation are partially independent of increase in body mass. Such improvements, along with appropriate adjustment for body mass, need to be taken into account when comparing performance of maturing athletes.

Before prescribing a specific training program to youth, both determining the contribution of neuromuscular capabilities to performance and the effect of maturity on training and detraining adaptations was thought important to understand as it had not been documented to this point. The contribution of strength and power to sprint performance in maturing athletes was investigated in Chapter 8. Sprint time was 5-6% faster Pre to Mid and Mid to Post PHV before adjustment. The group differences in scaling factors of

strength and power for sprint performance were generally trivial to small but unclear, so a single scaling factor was calculated for 1RM strength (-0.16 %/%) and for peak power (-0.20 %/%). The increase in sprint performance Pre to Mid PHV became small (1.9%) and trivial but unclear (0.9%) after adjustment for 1RM and peak power respectively, while the increases Mid to Post PHV became moderate (3.4% and 3.0% respectively). Percent differences in strength or power have percent effects on sprint performance that are similar at different stages of maturity. These relationships explain most of the maturity related improvements in sprint performance before PHV but only some improvements after. These findings enabled some guiding principles for the training of the youth athlete, for example training for speed during puberty should develop capabilities additional to strength and power.

To further inform training prescription, the effect of maturation on strength training and detraining adaptations in 11 to 15 years olds was investigated. The mean training effects on 1RM (3.6 to 10%), power measures (11 to 20 %), horizontal jump (6.5 to 7.4 %) and sprint times (-2.1 to -4.7 %) ranged from small to large, with generally greater changes in Mid- and Post-PHV groups were observed. Changes in force-velocity relationships reflected generally greater increases in strength at faster velocities. In the detraining period the Pre-PHV group showed greatest (complete) loss of strength and power gains, the post-PHV group showed some loss of sprint performance, but all groups maintained or improved horizontal jump. Strength training was less effective for strength, power and speed development in athletes before the growth spurt. The main finding was that maintenance programs are needed for most aspects of explosive performance following strength training, especially for strength and power before the growth spurt and for sprint speed after the growth spurt.

In conclusion, isointerital assessment of force-velocity-power profiling and maximal strength can be conducted in youth after a familiarization. However, maturity status and body mass should be accounted for before any conclusions are detailed on the neuromuscular capabilities of a young athlete as both maturity and body mass were found to influence performance. Practitioners should seek methods to improve both strength and power to enhance sprint performance in youth, but power training tended to be of greater effect than strength training to enhance this athletic characteristic, while maturity seems to play a role in the development of qualitative characteristics (e.g. inter muscular coordination) responsible for sprint performance. A strength training program was

beneficial in improving vertical strength, vertical and horizontal power, acceleration and maximal speed across different maturity groups, but practitioners should consider the integration of other training methods that may be more suitable to athlete performance prior to the growth spurt and ensure that maintenance or continuous programming for athletic development are being implemented in youth.

Limitations

Long-term athlete development is a continuous, multi-dimensional and complex process. This thesis only focused on a specific aspect of athlete development. Many individual (e.g. genetics, motivation, etc.) as well as environmental factors (equipment, coaching, supportive parents, etc.) will influence the individual's progress and development. We acknowledge that most of the research undertaken in this thesis was cross-sectional rather than longitudinal and therefore failed to capture many factors that may influence power development over a long period of time. Cross-sectional designs were preferred because of the limited repeated access to a youth population and other researchers have used similar approaches. Furthermore, any benefits associated with resistance training in youth should be contextualized with respect to the training history, amount of current training and ethnicities who volunteered in our investigations. That is, individual results will vary from mean trends and conclusions observed on analysis of the aggregated data.

Categorizing athletes into different maturity groups via a non-invasive measurement of PHV and uneven distribution of subjects in those groups might introduce sources of error. Usually PHV is determined retrospectively using longitudinal data points, but this method does not allow instantaneous classification of athletes by maturity groups for cross-sectional design purposes and also contains some source of error. For instance, stature might be recorded every three months and PHV identified, but PHV could have occurred anywhere in these three months. We replicated procedures published previously and believe that the small standard deviation in the determination of maturation in each group, the additional assessment of maturity status using percentage of predicted adult stature and the difference in leg length, height and body mass data between the groups, indicated that the measurement of subjects maturation were relatively homogeneous and accurate.

To measure the kinematics and kinetics of ballistic loaded squats on a supine leg press and assess the force-velocity-power profile in youth, a force plate underneath the foot

would have been the gold standard approach. However, we were unable to develop such a tool and the use of linear position transducer technology was preferred. The use of the linear position transducer as the principal means of data collection could be interpreted as a limitation of this thesis, but the strong relationship between this technology and force plate technology validates our methodological approach.

Estimating 1-RM at a velocity recorded in a different movement (i.e. bench press and squat), and performed by a different population, can be viewed as a limitation of this thesis. To address this issue, the correlation between completed 1-RM and estimated one 1-RM from our pilot study as well as the difference between the two measurement has been reported in the method section of chapter 5. Furthermore, the discussion in chapter 5 addressed this limitation and its contributing factors. It is possible that less trained subjects or children were likely to complete their 1RM at a slower speed than trained athletes or adults due to neuromuscular inhibition. However, given the high correlation between estimated 1RM at 0.23 m.s^{-1} and true 1RM and the minimal absolute difference between the two measures in the pilot study, there is strong evidence to support the validity of the 1-RM measure in this thesis.

The training intervention improved both vertical and horizontal power, and sprint performance as expected given the choice of the exercises in the program. However, we did not include a direct measure of horizontal and vertical power, as the force plate was defective for the post training testing session. Nonetheless, the findings from our thesis should assist coaches involved in athlete development to better monitor and understand changes in force-velocity-power profiling and maximal strength associated with growth and maturation. Furthermore, the results should assist the design of models for long-term sport-specific power development.

Finally, there was no control group in our training study. There might be some contention that greater improvement of some dependent variables in a maturity group may have been due to natural development rather than greater training dose-response. The inclusion of a detraining phase provided some insight into the natural development of each of the groups and possible influence on training effect. The meaningful difference in decay of 1RM and Pmax between Pre PHV and Mid/Post PHV, would suggest that strength and power may have a greater natural development around and after PHV. This finding is in accordance with the natural development of strength and power reported in this thesis and elsewhere and is discussed in Chapter 9.

Practical applications

The primary purpose of the thesis was to improve the body of knowledge about the effect of growth and maturation and a specific training intervention on maximal strength, force-velocity-power profiling and sprint performance in youth. While the development of these athletic characteristics is dependent on a multitude of factors, the main conclusion of this study was that maturity had an influence on the timing and tempo of these characteristics of development as well as a training dose-response relationship and rate of decay.

Concentric kinematics and kinetics in vertical and horizontal CMJ's and ballistic loaded squat jump on a supine leg press can be reliably used to monitor the young athlete regardless of maturity between 11 and 15 years old, however a familiarization session is recommended. Due to movement variability associated with the eccentric phase, only eccentric mean power can be used confidently to monitor eccentric capability. Monitoring eccentric mechanics is of considerable importance in youth training as it is associated with better ensuing concentric action and plays a role in injury prevention. Since different training regimes may elicit various adaptations, the ability to monitor both eccentric and concentric capability is appealing as it improves understanding of SSC performance.

The low variability of the force-velocity relationship across different loads provides a useful tool to explore force and velocity specific adaptation, resulting from different loading and subsequent training velocities. Using the same loading protocol, both power-load and power-velocity relationships can be calculated relatively quickly and reliably, and can be used to predict Pmax for training purposes. Furthermore, the predicted 1RM using the load-velocity relationship during the loading protocol appeared to be an excellent alternative to standard 1RM testing, since a number of neuromuscular capabilities can be assessed simultaneously rather than the 1RM only.

Given their predictive ability, maturity and body mass were taken into account when interpreting explosive performance of young athletes. Adjustment of maturity status and body mass to interpret force-velocity-power and maximal strength capability provided greater insight of the qualitative and quantitative neuromuscular factors responsible for the natural power development and its component parts (force-velocity) in youth. But, to accurately account for body mass when comparing children of different body sizes, variable specific allometric exponents need to be determined by the practitioner. Previous specific theoretical scaling models of body mass for force, power or speed that assume geometric

similarity across all youth populations would seem problematic, given the results of this thesis. The scaling factors need to be determined over a large sample size before they can be used confidently in practical settings or otherwise need to be calculated for every new sample. Also, practitioners should not compare athletes of different maturity status with the assumption that adjustment for body mass accounts for all maturational effects on strength, power and velocity capabilities, because qualitative factors were also responsible for the difference in performance between groups.

The changes in the force-velocity-power profile, maximal strength and speed during the maturity window of two and half years demonstrated the importance of taking into account the maturity status of young athletes when assessing physical performance. Coaches must be mindful that athletes of the same age may differ considerably in maturity, which can affect physical performance and skew talent identification. The development of power was associated not only with a force increase during maturation but also with a change in velocity capability, as expressed by the force-velocity relationship. Around PHV, there was a reduced ability to utilise the same relative percentage of maximal force at high velocity compared to the other two groups, which affected the development of power. From these findings it may be inferred that maturity-specific training programs should be considered. Prior to the onset of PHV, training should focus on developing the qualitative properties of the neuromuscular system to both enhance force and velocity capability of muscle, while Post PHV training may also consider training to increase muscle mass. Most importantly, to increase power and reduce the negative shift of the force-velocity relationship, training at the onset of PHV should concentrate on fast velocity movement and high rates of force development with movements that require a considerable level of inter-muscular coordination.

Independently of strength, power and anthropometric characteristics, the maturity effect on sprint performance was greater from Mid to Post PHV compared to Pre to Mid PHV, suggesting that maturity dependant factors important for sprinting, such as running mechanics, may progress faster during this period and be emphasised in training. Practitioners can expect that a training- or growth-induced improvement in vertical strength or power of 10% at any stage of maturation will produce a ~1.5-2% improvement on sprint performance in youth. The similar transference of strength and power into sprint performance provided no rationale to favour training programs targeting gains in strength or power to enhance sprint performance in youth. Furthermore, the apparently low

183

transference of vertical strength and power into sprint performance highlighted the need to include tests and exercises that target horizontal force production to diagnose and enhance elements of sprint performance.

According to the training emphasis concept, training periodization in youth should be based on the best method in a given maturity status to optimise adaptation. The strength training program implemented across different maturity groups was beneficial in improving vertical strength, vertical and horizontal power, acceleration and maximal speed. However, the magnitude of training and detraining as well as mechanical adaptations were maturity dependent. The maturity specific force, velocity and power adaptations to training and detraining have important implications to the natural development of these neuromuscular characteristics during growth and maturation. Strength training was more beneficial at enhancing Pmax and concurrently acceleration in Mid and Post PHV compared to Pre PHV. Rather than strength training, activities providing a velocity stimulus may be more valuable for athletes prior to PHV to develop power and speed. Regardless, practitioners should primarily concentrate on movement competency and include bilateral and unilateral vertical and horizontal force production exercises to optimally enhance all aspects of explosive athletic performance.

Future research

Future research could target five different areas of power development in the long-term athlete development process. First, the force-velocity-power profiling of the young athlete in the current thesis was vertical in nature, while most activities on the field are multi-planar. Developing force-velocity-power profiles in youth during sprinting using non-motorised treadmills and radar guns would contribute to the advancement of the knowledge in this area. Such testing could be used to demonstrate the mechanical transference of vertical or horizontal strength/power adaptations into sprint performance. Additionally, having a measure of rate of power development would seem relevant, considering that most movements in team-sport include fast ground contact time and require quick power production. This variable would be of particular interest when comparing power and strength training adaptations.

Secondly, the current thesis demonstrated the role of maturity in the development of force-velocity-power, maximal strength and speed capability, but failed to measure any

qualitative neuromuscular changes associated with maturation. Future investigations are needed to explore qualitative factors (fibre type composition, glycolytic ability, motor coordination, motor unit activation), which may contribute to the maturity effect on power development. As athlete development is dynamic and longitudinal in nature, future research investigating the change in power and its components over several years would provide additional information to the cross-sectional designs employed in the current thesis. Sport specific training influences power development, meaning that longitudinal research should be sport-specific and compared to a general population. Both the effect of maturation and sport-specific training on power development could be investigated with this type of research design. Training intervention on players could further disentangle the effect of sport-specific training and additional neuromuscular training on power development.

From the review of literature, it was unclear if a specific training method was more effective to enhance power at a given maturity status. The fourth area of future research focus could investigate the effects of different training methods on athletes of the same maturity status. These findings would guide the implementation of training emphasis periods throughout the athlete development pathway. Furthermore, the current thesis only investigated the dose-response relationship of strength training across different maturity groups. To inform a long-term development model of power, the dose-response relationship of other training modes needs to be implemented and quantified across different maturity groups. In general, research in the area of dose-response relationship, would benefit coaches and practitioners by providing important scientific knowledge about the loading parameters needed to induce changes in youth of different maturity status.

The final focus of future research could be on the specific power requirements and development of certain sports. The subjects in the series of studies in this thesis were drawn from different athletic populations. Investigating the force-velocity-power profile of a "talent pool" specific to a sport, such as soccer, may provide normative data/benchmarks for these measures that are specific to the sport. Ultimately, the importance of a physical characteristic such as power, should reflect the demands of the game. As a sport requires multiple athletic qualities, an athlete/player long-term development model should be sport specific to match the different athletic requirements and should include monitoring progress against maturity and sport specific benchmarks.

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Appendices

Appendix 1: Ethics approval

AUT UNIVERSITY
TE WĀNANGA ARONUI O TAMAKI MAKAU RAU

MEMORANDUM

Auckland University of Technology Ethics Committee (AUTEC)

To: John Cronin
From: **Charles Grinter** Ethics Coordinator, AUTEC
Date: 6 July 2010
Subject: Ethics Application Number 10/75 **The reliability of kinematic and kinetic jump variables in children of different maturity status.**

Dear John

Thank you for providing written evidence as requested. I am pleased to advise that it satisfies the points raised by the Auckland University of Technology Ethics Committee (AUTEC) at their meeting on 10 May 2010 and that on 5 July 2010, I approved your ethics application. This delegated approval is made in accordance with section 5.3.2.3 of AUTEC's *Applying for Ethics Approval: Guidelines and Procedures* and is subject to endorsement at AUTEC's meeting on 9 August 2010.

Your ethics application is approved for a period of three years until 5 July 2013.

I advise that 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/research/research-ethics*. When necessary this form may also be used to request an extension of the approval at least one month prior to its expiry on 5 July 2013;

- A brief report on the status of the project using form EA3, which is available online through *http://www.aut.ac.nz/research/research-ethics*. This report is to be submitted either when the approval expires on 5 July 2013 or on completion of the project, whichever comes sooner;

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 reminded that, as applicant, you are responsible for ensuring that research undertaken under this approval occurs within the parameters outlined in the approved application.

Please note that AUTEC grants ethical approval only. If you require management approval from an institution or organisation for your research, then you will need to make the arrangements necessary to obtain this. Also, if your research is undertaken within a jurisdiction outside New Zealand, you will need to make the arrangements necessary to meet the legal and ethical requirements that apply within that jurisdiction.

When communicating with us about this application, we ask that you use the application number and study title to enable us to provide you with prompt service. Should you have any further enquiries regarding this matter, you are welcome to contact Charles Grinter, Ethics Coordinator, by email at ethics@aut.ac.nz or by telephone on 921 9999 at extension 8860.

On behalf of the AUTEC and myself, I wish you success with your research and look forward to reading about it in your reports.

Yours sincerely

On behalf of Madeline Banda, Executive Secretary
Auckland University of Technology Ethics Committee

Cc: Cesar Meylan cesar.meylan@aut.ac.nz

M E M O R A N D U M
Auckland University of Technology Ethics Committee (AUTEC)

To:	John Cronin
From:	**Charles Grinter** Ethics Coordinator, AUTEC
Date:	2 July 2010
Subject:	Ethics Application Number 10/74 **The reliability and validity of maximum strength and force-velocity-power profiling in males of different maturity status.**

Dear John

Thank you for providing written evidence as requested. I am pleased to advise that it satisfies the points raised by the Auckland University of Technology Ethics Committee (AUTEC) at their meeting on 10 May 2010 and that on 1 July 2010, I approved your ethics application. This delegated approval is made in accordance with section 5.3.2.3 of AUTEC's *Applying for Ethics Approval: Guidelines and Procedures* and is subject to endorsement at AUTEC's meeting on 9 August 2010.

Your ethics application is approved for a period of three years until 1 July 2013.

I advise that 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/research/research-ethics*. When necessary this form may also be used to request an extension of the approval at least one month prior to its expiry on 1 July 2013;

- A brief report on the status of the project using form EA3, which is available online through *http://www.aut.ac.nz/research/research-ethics*. This report is to be submitted either when the approval expires on 1 July 2013 or on completion of the project, whichever comes sooner;

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 reminded that, as applicant, you are responsible for ensuring that research undertaken under this approval occurs within the parameters outlined in the approved application.

Please note that AUTEC grants ethical approval only. If you require management approval from an institution or organisation for your research, then you will need to make the arrangements necessary to obtain this.

When communicating with us about this application, we ask that you use the application number and study title to enable us to provide you with prompt service. Should you have any further enquiries regarding this matter, you are welcome to contact Charles Grinter, Ethics Coordinator, by email at ethics@aut.ac.nz or by telephone on 921 9999 at extension 8860.

On behalf of the AUTEC and myself, I wish you success with your research and look forward to reading about it in your reports.

Yours sincerely

On behalf of Madeline Banda, Executive Secretary
Auckland University of Technology Ethics Committee

Cc: Cesar Meylan cesar.meylan@aut.ac.nz

M E M O R A N D U M

Auckland University of Technology Ethics Committee (AUTEC)

To: John Cronin
From: **Madeline Banda** Executive Secretary, AUTEC
Date: 3 June 2010
Subject: Ethics Application Number 10/55 **Coordination-agility vs strength-power training in prepubescent athletes.**

Dear John

Thank you for providing written evidence as requested. I am pleased to advise that it satisfies the points raised by the Auckland University of Technology Ethics Committee (AUTEC) at their meeting on 12 April 2010 and that on 1 June 2010 I approved your ethics application, including a minor amendment allowing recruitment from soccer clubs. This delegated approval is made in accordance with section 5.3.2.3 of AUTEC's *Applying for Ethics Approval: Guidelines and Procedures* and is subject to endorsement at AUTEC's meeting on 12 July 2010.

Your ethics application is approved for a period of three years until 1 June 2013.

I advise that 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/research/research-ethics*. When necessary this form may also be used to request an extension of the approval at least one month prior to its expiry on 1 June 2013;

- A brief report on the status of the project using form EA3, which is available online through *http://www.aut.ac.nz/research/research-ethics*. This report is to be submitted either when the approval expires on 1 June 2013 or on completion of the project, whichever comes sooner;

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 reminded that, as applicant, you are responsible for ensuring that research undertaken under this approval occurs within the parameters outlined in the approved application.

Please note that AUTEC grants ethical approval only. If you require management approval from an institution or organisation for your research, then you will need to make the arrangements necessary to obtain this. Also, if your research is undertaken within a jurisdiction outside New Zealand, you will need to make the arrangements necessary to meet the legal and ethical requirements that apply within that jurisdiction.

When communicating with us about this application, we ask that you use the application number and study title to enable us to provide you with prompt service. Should you have any further enquiries regarding this matter, you are welcome to contact Charles Grinter, Ethics Coordinator, by email at ethics@aut.ac.nz or by telephone on 921 9999 at extension 8860.

On behalf of the AUTEC and myself, I wish you success with your research and look forward to reading about it in your reports.

Yours sincerely

Madeline Banda
Executive Secretary
Auckland University of Technology Ethics Committee

Cc: Cesar Meylan cesar.meylan@aut.ac.nz

M E M O R A N D U M
Auckland University of Technology Ethics Committee (AUTEC)

To: John Cronin
From: **Dr Rosemary Godbold and Madeline Banda** Executive Secretary, AUTEC
Date: 7 June 2011
Subject: Ethics Application Number 11/122 **The effect of high-load low-velocity strength training on power and sprint performance in children of different maturity status.**

Dear John

Thank you for providing written evidence as requested. We are pleased to advise that it satisfies the points raised by the Auckland University of Technology Ethics Committee (AUTEC) at their meeting on 9 May 2011 and that on 30 May 2011, we approved your ethics application. This delegated approval is made in accordance with section 5.3.2.3 of AUTEC's *Applying for Ethics Approval: Guidelines and Procedures* and is subject to endorsement at AUTEC's meeting on 27 June 2011.

Your ethics application is approved for a period of three years until 30 May 2014.

We advise that 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/research/research-ethics/ethics. When necessary this form may also be used to request an extension of the approval at least one month prior to its expiry on 30 May 2014;

- A brief report on the status of the project using form EA3, which is available online through http://www.aut.ac.nz/research/research-ethics/ethics. This report is to be submitted either when the approval expires on 30 May 2014 or on completion of the project, whichever comes sooner;

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 reminded that, as applicant, you are responsible for ensuring that research undertaken under this approval occurs within the parameters outlined in the approved application.

Please note that AUTEC grants ethical approval only. If you require management approval from an institution or organisation for your research, then you will need to make the arrangements necessary to obtain this. Also, if your research is undertaken within a jurisdiction outside New Zealand, you will need to make the arrangements necessary to meet the legal and ethical requirements that apply within that jurisdiction.

When communicating with us about this application, we ask that you use the application number and study title to enable us to provide you with prompt service. Should you have any further enquiries regarding this matter, you are welcome to contact Charles Grinter, Ethics Coordinator, by email at ethics@aut.ac.nz or by telephone on 921 9999 at extension 8860.

On behalf of AUTEC and ourselves, we wish you success with your research and look forward to reading about it in your reports.

Yours sincerely

Dr Rosemary Godbold and Madeline Banda
Executive Secretary
Auckland University of Technology Ethics Committee

Cc: Cesar Meylan cesar.meylan@aut.ac.nz

Appendix 2: Subject information sheet

Participants Information Sheet

AUT UNIVERSITY
TE WĀNANGA ARONUI O TAMAKI MAKAU RAU

Date Information Sheet Produced:

10th July 2010

Project Title

The stability of vertical and horizontal jump measures in children of different age

An Invitation

I, César Meylan, am a Doctoral candidate at the AUT University in Auckland, as well as a Fitness Football coordinator for New Zealand Football and a coach in the Long Term Athlete Development programme at the Milliennium Institute of Sport and Health,

I would like to invite you to be part of a study looking at jumping. You can choose either to participate or not participate in the study and your choice will not affect your training. If you start the study please understand that you may stop at any time without any problems.

Travis McMaster, a doctoral student in the School of Sport and Recreation at AUT University, will be your point of contact if you have any further questions regarding this research. His contact details are described later in this document. He will also be helping to record the data of the jumps

What is the purpose of this research?

The purpose of this study is to determine if children and adolescent jump the same way every time they are tested.

How was I chosen for this invitation?

You are a young athlete aged between 10 and 17 years old that is active and engaged in the LTAD programme.

What will happen in this research?

You will be doing two types of jumps on three occasions on a force plate (see picture). You will practice these jumps during training. On the first testing session, your standard body composition measurements (height, weight, etc) will be taken followed by the normal athletic tests. These tests include three vertical and three horizontal countermovement jumps with arms on hips with 30 s recovery between jumps. Prior to testing, you will perform a 10-minute warm-up consisting of 5 minutes of jogging and 5 minutes of dynamic movements (skipping, lunging).
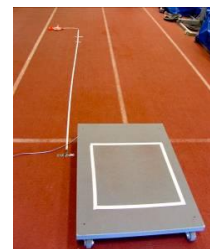
What are the risks?

The anticipated discomforts and risks from participating in this testing differ very little to your regular testing and in fact should be reduced given that only your jumps and not sprints will be assessed. There is a risk of injuring yourself if a proper warm-up is not used prior the testing. However the probability of this occurring is no more likely than during normal testing sessions.

How will the risks be alleviated?

We will also ask you to warm-up and stretch properly before testing and training. You should also keep warm and drink fluids throughout the testing and training sessions.

Immediately after each test, you will be asked to actively recover by walking, which will help you recover. Please let the tester know if you feel that you need more time to recover between tests. Finally, please tell the tester, if you have a current injury or have had an injury within the last four months that might affect you sprinting or jumping.

What are the benefits?

By being involved in this study, you are helping us establish good measures of jumping ability. Also you will have information about your jump height and length.

What happens if I am injuried?

In the unlikely event of an injury as a result of you jumping in this study you will receive medical help that will depend on the nature of your injury e.g. see a doctor. There are medical facilities and personnel at the facility i.e. Millennium.

How will my privacy be protected?

Your results will be kept private as only César Meylan (main researcher) and John Cronin (his supervisor) will see them and then your results will be put with other athletes data and then analyzed. The data and assent forms will be kept in a secured place for 10 years.

What are the costs of being in this study?

There are no costs of being in this study apart from your time for testing. Your parents or legal guardians can be present at your testing days, if you wish them to be there.

What opportunity do I have to consider this invitation?

After you have read through this form, you will have time to talk to your parents or legal guardians and the researcher to ask any questions you would like to know about the study. After your questions have been answered, you will need to decide whether or not you would like to be involved in the study. If you would like to participate in this study, then you fill in and sign the attached *Assent Form* if you are under 16 years old or the *Consent Form for Participants* if you are 16 to 17 years old. All forms needs to be returned to Travis McMaster with the *Parent or Guardian Consent Form* prior to starting any of the tests. Please note you are not able to participate in this research if you and your parents or legal guardians have not filled out and signed the forms. If you do not wish to be involved in this research, please let the researcher know also.

Will I receive feedback on the results of this study?

Yes, you can receive a summary of your individual results once the information is ready. Please tick the box on the *Consent Form* if you would like this information.

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

Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor, Dr John Cronin, john.cronin@aut.ac.nz, telephone: 09 921 9999, extension 7523.

Concerns regarding the conduct of the research should be notified to the Executive Secretary, AUTEC, Madeline Banda, madeline.banda@aut.ac.nz, telephone: 09 921 9999, extension 8044.

Approved by the Auckland University of Technology Ethics Committee on: 6 July 2010
AUTEC Reference number 10/75

Participants Information Sheet

Date Information Sheet Produced:

30th July 2010

Project Title

The reliability and validity of maximum strength and force-velocity-power profiling in males of different maturity status

An Invitation

I, César Meylan, am a Doctoral candidate at the AUT University in Auckland, as well as a Fitness Football coordinator for New Zealand Football and a coach in the Long Term Athlete Development programme at the Millennium Institute of Sport and Health,

I would like to invite you to be part of a study looking at strength and power. You can choose either to participate or not participate in the study and your choice will not affect your training. If you start the study please understand that you may stop at any time without any problems.

Travis McMaster, a doctoral student in the School of Sport and Recreation at AUT University, will be your point of contact if you have any further questions regarding this research. His contact details are described later in this document.

What is the purpose of this research?

The purpose of this project is to determine if you have the same leg strength and power every time you are tested and if your strength level is related to sprinting and jumping.

How was I chosen for this invitation?

You are a young athlete aged between 10 and 17 years old that is active and engaged in the LTAD programme or in a soccer club.

What will happen in this research?

You will have to come five times to the Millennium Institute of Sport and Health on the North Shore. The first time will be a session during which you will practice the tests. During this session we will also take some body such as height, weight etc. During the next three test sessions you will have to do a maximal push on a weight machine for the legs (see picture) and five fast push movement on the same machine with weight in relation with your bodyweight. In the last testing session we will test your vertical and horizontal jumps and 30 m sprint. Before every testing session, you will perform a 10-minute warm-up. The first and last sessions will take 40 min and the three other sessions will take 20 min.

What are the risks?

The risks from participating in this testing differ very little to your regular exercising. There is a risk of injuring yourself if you do not warm-up properly. However this is no more likely than when you train for your sport.

How will the risks be alleviated?

We will be ask you to warm-up and stretch properly before testing and training. You should also keep warm and drink fluids throughout the testing and training sessions.

Immediately after each test, you will be asked to walk which will help you recover. Please let the tester know if you feel that you need more time to recover between tests. Finally, please tell the tester, if you have a current injury or have had an injury within the last four months that might affect you sprinting or jumping.

What are the benefits?

By being involved in this study, you will know your maximal leg strength, power and measures of your jump height and length as well as speed. You are also helping us establish measures of strength and power that we can use across many different athletes and sports.

What happens if I am injuried?

In the unlikely event of an injury as a result of you running in this study you will receive medical help that will depend on the nature of your injury e.g. see a doctor. There are medical facilities and personnel at the facility i.e. Millennium.

How will my privacy be protected?

Your results will be kept private as only César Meylan (main researcher) and John Cronin (his supervisor) will see them and then your results will be put with other athletes data to be analyzed. Your name will always remain secret.

What are the costs of being in this study?

There are no costs of being in this study apart from your time for testing. Your parents or legal guardians can be present at your testing days, if you wish them to be there.

What opportunity do I have to consider this invitation?

After you have read through this form, you will have time to talk to your parents or legal guardians and the researcher to ask any questions you would like to know about the study. After your questions have been answered, you will need to decide whether or not you would like to be involved in the study. If you would like to participate in this study, then you fill in and sign the attached *Assent Form* if you are under 16 years old or the *Consent Form for Participants* if you are 16 to 17 years old. All forms needs to be returned to Travis McMaster with the *Parent or Guardian Consent Form* prior to starting any of the tests. Please note you are not able to participate in this research if you and your parents or legal guardians have not filled out and signed the forms. If you do not wish to be involved in this research, please let the researcher know also.

Will I receive feedback on the results of this study?

Yes, you can receive a summary of your individual results once the information is ready. Please tick the box on the *Consent Form* if you would like this information.

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

Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor, Dr John Cronin, john.cronin@aut.ac.nz, telephone: 09 921 9999, extension 7523.Concerns regarding the conduct of the research should be notified to the Executive Secretary, AUTEC, Madeline Banda, madeline.banda@aut.ac.nz, telephone: 09 921 9999, extension 8044.

Participants Information Sheet

![AUT University logo]

Date Information Sheet Produced:

6 June 2010

Project Title

Coordination-agility vs. strength-power training in young athletes

An Invitation

I, César Meylan, am a Doctoral student at the AUT University in Auckland, as well as a Fitness Football coordinator for New Zealand Football and a coach in the Long Term Athlete Development programme at the Millennium Institute of Sport and Health,

I would like to invite you to be part of a study on the effects of two different types of training or usual sport activity on your jump, speed and agility performance. You will be part of the group that does the special training. You can choose either to participate or not participate in the study and your choice will not affect your training. If you choose to be involved in the training please understand that you may stop at any time without any problems.

Travis McMaster, a doctoral student in the School of Sport and Recreation at AUT University, will be your point of contact if you have any further questions regarding this research. His contact details are described later in this document.

What is the purpose of this research?

The purpose of this project is to examine the effect of various types of training or normal sport activity on your jump, speed and agility.

How was I chosen for this invitation?

You are a young athlete that is active and playing sport

What will happen in this research?

You will be tested before and after 8 weeks of training. During these testing sessions some body measurements such as height, weight etc. will be taken first followed by you performing a vertical jump, a horizontal jump, 30 meter sprint and an agility test. Prior to testing, you will follow a 10-minute warm-up. During the eight weeks between testing, you will follow a training programme during the LTAD programme and other kids outside the programme will follow their regular sports activity. The training programme will try to improve your coordination-agility or your strength-power. Training will be fun and challenging. Sessions will last for 20 minutes three times per week during the LTAD programme.

What are the risks?

The risks are similar to what you usually experience in the LTAD programme or at school. You may have some muscle soreness or heavy breathing but this is happens with most forms of hard exercise. Any soreness or hard breathing should end quite quickly during the rest period.

You will be asked to wear a short and singlet so as we can measure weight, height and skinfolds. Your parents/guardians can stay in the room at all times if you feel uncomfortable.

All training session will match your abilities and therefore you should not be more sore or tired than any regular LTAD or school session you do.

How will the risks be alleviated?

We will also ask you to warm-up and stretch properly before testing and training. You should also keep warm and drink fluids throughout the testing and training sessions.

Immediately after each test, you will be asked to actively recover by walking, which will help you recover. Please let the tester know if you feel that you need more time to recover between tests. Finally, please tell the tester, if you have a current injury or have had an injury within the last four months that might affect you sprinting or jumping.

What are the benefits?

By being involved in this study, you are helping us understand what are the best training methods for young athletes to improve jumping, sprinting and agility. Also if you are interested we can give you a summary of your results.

What happens if I am injuried?

In the unlikely event of an injury as a result of you running in this study you will receive medical help that will depend on the nature of your injury e.g. see a doctor. There are medical facilities and personnel at the facility i.e. Millennium.

How will my privacy be protected?

Your results will be kept private as only two people will see them and then your results will be put with other athletes data and then analyzed.

What are the costs of being in this study?

There are no costs of being in this study apart from your time for testing. Your parents can be present at your testing days, if you wish them to be there.

What opportunity do I have to consider this invitation?

After you have read through this form, you will have time to talk to your parents and the researcher to ask any questions you would like to know about the study. After your questions have been answered, you will need to decide whether or not you would like to be involved in the study. If you would like to participate in this study, then you fill in and sign the attached *Assent Form* and return it to Travis McMaster with the *Parent or Guardian Consent Form* prior to starting any of the tests. Please note you are not able to participate in this research if you and your parents have not filled out and signed the forms. If you do not wish to be involved in this research, please let the researcher know also.

Will I receive feedback on the results of this study?

Yes, you can receive a summary of your individual results once the information is ready. Please tick the box on the *Consent Form* if you would like this information.

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

Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor, Dr John Cronin, john.cronin@aut.ac.nz, telephone: 09 921 9999, extension 7523.

Concerns regarding the conduct of the research should be notified to the Executive Secretary, AUTEC, Madeline Banda, madeline.banda@aut.ac.nz, telephone: 09 921 9999, extension 8044.

Participants Information Sheet

AUT
UNIVERSITY
TE WĀNANGA ARONUI O TAMAKI MAKAU RAU

Date Information Sheet Produced:

July 19th 2011

Project Title

The effect of strength training on muscle strength, jump and sprint performance in children 12-15 years old.

An Invitation

I, César Meylan, am a student at the AUT University in Auckland, as well as a Fitness Football Manager for New Zealand Football and Fitness coach of the Women National Football Team,

I would like to invite you to be part of a study on the effects strength training or usual sport activity on your strength, jump, and speed performance. You will be put randomly either to the group who is doing the special training or the group that carry on its normal sporting activity. You can choose either to participate or not participate in the study. If you choose to be involved in the training please understand that you may stop at any time without any problems.

What is the purpose of this research?

The purpose of this project is to examine the effect of strength training or normal sport activity on your leg strength, jump and speed.

How was I chosen for this invitation?

You are a young athlete that is active and playing sport

What will happen in this research?

You will be tested before and after a period of 8 weeks. The pre and post testing to the 8 weeks period will include two testing session. During the first day of testing, some body measurements such as height, weight etc. will be taken first followed by you performing five fast push movement on a leg press machine with weight in relation with your bodyweight. In the second testing session we will test your vertical and horizontal jumps and 30 m sprint. The same testing will be repeated after the 8 weeks. Before every testing session, you will perform a 15-minute warm-up. Each testing session will be between 30 and 45 minutes. During the eight weeks between testing, you will follow a strength training programme or continue your normal sporting activity depending on the group you will be in. Training will be fun and challenging with the purpose to make you stronger, more powerful and faster. Sessions will last for 45 minutes two times per week before or after school.

What are the risks?

The risks are similar to what you usually experience in clubs or at school. You may have some muscle soreness or heavy breathing but this is happens with most forms of hard exercise. Any soreness or hard

breathing should end quite quickly during the rest period. You will be asked to wear a short and singlet so as we can measure weight, height and skinfolds. Your parents/guardians can stay in the room at all times if you feel uncomfortable. All training session will match your abilities and therefore you should not be more sore or tired than any regular training session you do.

How will the risks be alleviated?

We will also ask you to warm-up and stretch properly before testing and training. You should also keep warm and drink fluids throughout the testing and training sessions. Immediately after each test, you will be asked to actively recover by walking, which will help you recover. Please let the tester know if you feel that you need more time to recover between tests. Finally, please tell the tester, if you have a current injury or have had an injury within the last four months that might affect you strength, sprinting or jumping.

What are the benefits?

By being involved in this study, you are helping us understand what are the best training methods for young athletes to improve strength, jumping, and sprinting. Also if you are interested we can give you a summary of your results.

What happens if I am injuried?

In the unlikely event of an injury as a result of you running in this study you will receive medical help that will depend on the nature of your injury e.g. see a doctor. There are medical facilities and personnel at the facility i.e. Millennium.

How will my privacy be protected?

Your results will be kept private as only two people will see them and then your results will be put with other athletes data and then analyzed.

What are the costs of being in this study?

There are no costs of being in this study apart from your time for testing. Your parents can be present at your testing days, if you wish them to be there.

What opportunity do I have to consider this invitation?

After you have read through this form, you will have time to talk to your parents and the researcher to ask any questions you would like to know about the study. After your questions have been answered, you will need to decide whether or not you would like to be involved in the study. If you would like to participate in this study, then you fill in and sign the attached *Assent Form* and return it to César Meylan with the *Parent or Guardian Consent Form* prior to starting any of the tests. Please note you are not able to participate in this research if you and your parents have not filled out and signed the forms. If you do not wish to be involved in this research, please let the researcher know also.

Will I receive feedback on the results of this study?

Yes, you can receive a summary of your individual results once the information is ready. Please tick the box on the *Consent Form* if you would like this information.

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

Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor, Dr John Cronin, john.cronin@aut.ac.nz, telephone: 09 921 9999, extension 7523.

Concerns regarding the conduct of the research should be notified to the Executive Secretary, AUTEC, Madeline Banda, madeline.banda@aut.ac.nz, telephone: 09 921 9999, extension 8044.

Approved by the Auckland University of Technology Ethics Committee on 7th of June 2011, AUTEC Reference number 11/122

Parents and Legal Guardians Information Sheet

Date Information Sheet Produced:

10th July 2010

Project Title

The stability of vertical and horizontal jump measures in children of different age

An Invitation

I, César Meylan, am a Doctoral candidate at the AUT University in Auckland, as well as a Fitness Football coordinator for New Zealand Football and a coach in the Long Term Athlete Development programme at the Milliennium Institute of Sport and Health,

I would like to invite your child to participate in a research studying the The stability of vertical and horizontal jump measures in children of different age in prepubescent and pubescent athletes. His/her participation is entirely voluntary and whether or not he/she chooses to participate will neither advantage nor disadvantage him/her in relation to his/her training. Please understand that your son/daughter may withdraw at any time without any adverse consequences.

Travis McMaster, a doctoral student in the School of Sport and Recreation at AUT University, will be your point of contact if you have any further questions regarding this research. His contact details are described later in this document. He will also be helping to record the data of the jumps

What is the purpose of this research?

The purpose of this study is to determine the stability of vertical and horizontal jump measures in children of different age

How was my child chosen for this invitation?

Your child is a young athlete aged between 10 and 17 years old that is engaged in the long term athlete development programme at the Millennium Institute of Sport and Health. Your child should notify the researcher, if he has a current injury or has had an injury within the last four months that might affect his performance, or that might be worsened or aggravated by the required activity. If discomfort occurs during a movement and your child cannot perform the activity maximally, he will be excluded from the study.

What will happen in this research?

Your son/daughter will be assessed on three occasions on a force plate. He/she will receive a familiarization session of jump performed during training. On the first testing session, body composition measurements (skinfolds, girth, breath, height, sitting height, weight, height of second sacral vertebrae) will be taken first followed by physical performance tests. Performance tests will include three vertical
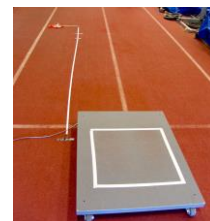
three horizontal countermovement jumps with arms on hips with 30 s recovery between jumps. Prior to testing, your child will undertake a 10-minute standardized warm-up consisting of five minutes of jogging followed by a series of dynamic movements (e.g. lunges and skipping). The testing duration will be of 40 min the first time and 20 min on testing occasion two and three.

What are the discomforts and risks?

The anticipated discomforts and risks from participating in this testing differ very little to the regular physical activity engaged in at LTAD. The main discomfort your child may experience during some of the testing and training is a mild soreness sensation in his/her legs. This response is normal and triggered by the onset of any exercise. As with training, the degree to which this occurs varies depending on your child's level of exertion, current fitness and personal tolerance to exercising. These symptoms should dissipate quite quickly during the recovery period assigned after each test.

The other possible discomfort is delayed onset of muscle soreness (DOMS) the following or subsequent two days after testing/training. However, your child is less likely to get DOMS after testing as your son/daughter will have enough time to recover in between trials. Any muscle soreness should dissipate within 3 to 5 days.

Participants will be asked to wear shorts and a singlet for the anthropometry measurements which can create a small discomfort. However, you can be in the room to reassure the child. In addition, all anthropometric measurement will be made following the guidelines outlined by the International Society for the Advanced of Kinoanthropometry.

How will these discomforts and risks be alleviated?

Your child will have the opportunity to familiarize him/herself with the testing procedures.

To reduce discomforts and risks from testing, your son/daughter will be asked to physically prepare him/herself prior to the first test by undertaking a warm up under supervision. It will also help if he/she also stays warm and drinks fluids throughout the testing and training sessions.

Immediately after each test, he/she will be asked to rest for 30 to 60 seconds to keep blood circulating and to assist with the breakdown of possible lactic acid – light walking is better than standing still or lying down. If your child needs more time to prepare or recover between tests, he/she should notify the researcher, as we are interested in measuring his/her best performance.

If your child does not feel able to complete the test requested, he/she should notify the researcher immediately and the testing will be terminated.

Finally, your son/daughter should notify the researcher, if he/she has a current injury or have had an injury within the last four months that might affect his/her performance, or that might be worsened or aggravated by the required activity. For example, a current knee injury would exclude him/her from the running as well as a current arm or shoulder injury. If discomfort occurs during a movement, your child will be recommended to withdraw from testing on that occasion.

What are the benefits?

By participating in this study, your child will help assess the reliability of practical methods to assess jump mechanics in youth sports. These methods can then be implemented to a wider group of athletes to monitor training.

What compensation is available for injury or negligence?

In the unlikely event of a physical injury as a result of your child's 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 child's privacy be protected?

The identity and results of each participant will be kept confidential. Only the researcher (César Meylan) and the primary supervisor (Prof. John Cronin) will analyze your results. Individual results are de-identified and usually pooled and presented as averages when presented in media. The data and consent forms will be kept in a secured place for 10 years.

What are the costs of participating in this research?

There are no costs to participation, apart from scheduling your and your child's time to be available for testing.

What opportunity does my child have to consider this invitation?

After he/she has read through this form, you and your child will have plenty of opportunity to ask any questions you would like about the study up to the first testing occasion. The initial testing session is scheduled to commence July 2010. The final testing day will be scheduled three-four weeks after the initial testing.

After you and your child's concerns have been satisfied, your son/daughter will need to decide whether or not he/she would like to participate in the research. As a parent or legal guardian, you can be present at all testing, if you and/or your child wish.

How do my child agree to participate in this research?

If your child would like to participate in this research, you need to sign the attached *Parents and Legal Guardians Consent Form*. Your child needs to fill in and sign the attached *Assent Form* if he is under 16 or the *Participant Consent Form* if he is 16 to 17 years old. All forms should be returned to Travis McMaster prior to participating in any of the tests for each project stage. Please note that your child is not able to participate in this research if you and your child have not filled out and signed the forms.

If your son/daughter does not wish to participate in this research, he/she should notify the researcher also. Please understand that your child may withdraw at any time without any adverse consequences.

Will my child receive feedback on the results of this research?

Yes, he/she can receive a summary of his/her individual results once the information is ready for distribution (around end August 2010). Please check the appropriate box on the *Consent Form* if you would like this information.

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

Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor, Dr John Cronin, john.cronin@aut.ac.nz, telephone: 09 921 9999, extension 7523.

Concerns regarding the conduct of the research should be notified to the Executive Secretary, AUTEC, Madeline Banda, madeline.banda@aut.ac.nz, telephone: 09 921 9999, extension 8044.

Whom do I or my child contact for further information about this research?

Please contact, Travis McMaster, t.mcmaster@aut.ac.nz, mobile 022 624 8050.

Student Researcher Contact Details:

César Meylan, cesar.meylan@aut.ac.nz, mobile 021 0255 0953

Project Supervisor Contact Details:

Dr John Cronin, john.cronin@aut.ac.nz, telephone: 09 921 9999, extension 7523.

**Approved by the Auckland University of Technology Ethics Committee on: 10th July 2010,
AUTEC Reference number 10/75**

Parents and Legal Guardians Information Sheet

Date Information Sheet Produced:

30th July 2010

Project Title

The reliability and validity of maximal strength and force-velocity-power profiling in males of different maturity status

An Invitation

I, César Meylan, am a Doctoral candidate at the AUT University in Auckland, as well as a Fitness Football coordinator for New Zealand Football and a coach in the Long Term Athlete Development programme at the Millennium Institute of Sport and Health,

I would like to invite your child to participate in a research studying the reliability and validity of maximal strength and force-velocity-power profiling in prepubescent and pubescent male athletes. Your child's participation is entirely voluntary and whether or not he chooses to participate will neither advantage nor disadvantage him in relation to his training. Please understand that your son may withdraw at any time without any adverse consequences.

Travis McMaster, a doctoral student in the School of Sport and Recreation at AUT University, will be your point of contact if you have any further questions regarding this research. His contact details are described later in this document.

What is the purpose of this research?

The purpose of this study is to determine the reliability and validity of maximal strength (one repetition maximum - 1RM) and force-velocity-power profiling in males of different maturity status.

How was my child chosen for this invitation?

Your child is a male young athlete aged between 10 and 17 years old that is engaged in the long term athlete development programme at the Millennium Institute of Sport and Health and/or part of a soccer club on the North Shore, Auckland. Your son should notify the researcher, if he has a current injury or has had an injury within the last four months that might affect his performance, or that might be worsened or aggravated by the required activity. If discomfort occurs during a movement and your child cannot perform the activity maximally, he will be excluded from the study.

What will happen in this research?

You son will be required for testing at the Millennium Institute of Sport and Health on the North Shore on five occasions. He will be assessed on three occasions on a supine squat machine (see picture) and one time on sprint and jump abilities. Prior to this, he will receive a familiarization session. During this familiarisation

session, anthropometric measurements (skinfolds, girth, breadth, height, sitting height, weight, height of second sacrum vertebrae) will be taken. In the first three testing sessions, the tests will include 1RM and explosive supine squats at five different relative loads to body weight (BW) on the supine squat machine: -20%BW, BW, 20%BW, 40%BW and 60%BW. In the last testing session, the same testing on the supine squat machine will be performed as well as three trials of vertical and horizontal countermovement jumps and three trials of a 30 m sprint. Prior to testing, your child will undertake a 10-minute standardized warm-up consisting of five minutes of jogging followed by a series of dynamic movements (e.g. lunges and skipping). The familiarisation session will be 40 min in duration, the three testing sessions on the supine squat machine will be 20 min and the last testing session including the jumping and sprinting performance will be 40 min.

What are the discomforts and risks?

The anticipated discomforts and risks from participating in this testing differ very little to the regular physical activity engaged in LTAD or soccer training. The main discomfort your child may experience during some of the testing and training is a mild soreness sensation in his/her legs. This response is normal and triggered by the onset of any exercise. As with training, the degree to which this occurs varies depending on your child's level of exertion, current fitness and personal tolerance to exercising. These symptoms should dissipate quite quickly during the recovery period assigned after each test.

The other possible discomfort is delayed onset of muscle soreness (DOMS) the following or subsequent two days after testing/training. However, your child is less likely to get DOMS after testing as your son/daughter will have enough time to recover in between trials. Any muscle soreness should dissipate within 3 to 5 days.

Participants will be asked to wear shorts and a singlet for the anthropometry measurements which may create small discomfort. However, you can be in the room to reassure the child. In addition, all anthropometric measurement will be made following the guidelines outlined by the International Society for the Advanced of Kinoanthropometry.

How will these discomforts and risks be alleviated?

Your child will have the opportunity to familiarize himself with the testing procedures.

To reduce discomforts and risks from testing, your son will be asked to physically prepare himself prior to the first test by undertaking a warm up under supervision. It will also help if he also stays warm and drinks fluids throughout the testing and training sessions.

Immediately after each test, he will be asked to rest for 30 to 60 seconds to keep blood circulating and to assist with the breakdown of possible lactic acid, light walking is better than standing still or lying down. If your child needs more time to prepare or recover between tests, he should notify the researcher, as we are interested in measuring his best performance.

If your child does not feel able to complete the test requested, he should notify the researcher immediately and the testing will be terminated.

Finally, your son should notify the researcher, if he has a current injury or has had an injury within the last four months that might affect his performance, or that might be worsened or aggravated by the required activity. For example, a current knee injury would exclude him from the running as well as a current arm or shoulder injury. If discomfort occurs during a sprint bout, your child will be recommended to withdraw from testing on that occasion.

What are the benefits?

By participating in this study, your child will help assess the reliability and validity of practical methods to assess force-velocity-power profiling in youth athletes. These methods can then be implemented to a wider group of athletes to monitor training.

What compensation is available for injury or negligence?

In the unlikely event of a physical injury as a result of your child's 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 child's privacy be protected?

The identity and results of each participant will be kept confidential. Only the researcher (César Meylan) and the primary supervisor (Prof. John Cronin) will analyze your results. Individual results are de-identified and usually pooled and presented as averages when presented in media.

What are the costs of participating in this research?

There are no costs to participation, apart from scheduling your and your child's time to be available for testing.

What opportunity does my child have to consider this invitation?

After he has read through this form, you and your child will have plenty of opportunity to ask any questions you would like about the study up to the first testing occasion. The initial testing session is scheduled to commence July 2010. The final testing day will be scheduled three-four weeks after the initial testing.

After you and your child's concerns have been satisfied, your son will need to decide whether or not he would like to participate in the research. As a parent or legal guardian, you can be present at all testing, if you and/or your child wish.

How do my child agree to participate in this research?

If your child would like to participate in this research, you need to sign the attached *Parents and Legal Guardians Consent Form*. Your child needs to fill in and sign the attached *Assent Form* if he is under 16 or the *Participant Consent Form* if he is 16 to 17 years old. All forms should be returned to Travis McMaster prior to participating in any of the tests. As I am a coach in the LTAD programme, Travis McMaster will act as a mediator. Please note that your child is not able to participate in this research if you and your child have not filled out and signed the forms.

If your son does not wish to participate in this research, he should notify the researcher also. Please understand that your child may withdraw at any time without any adverse consequences.

Will my child receive feedback on the results of this research?

Yes, he can receive a summary of his/her individual results once the information is ready for distribution (around end October 2010). Please check the appropriate box on the *Consent Form* if you would like this information.

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

Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor, Dr John Cronin, john.cronin@aut.ac.nz, telephone: 09 921 9999, extension 7523.

Concerns regarding the conduct of the research should be notified to the Executive Secretary, AUTEC, Madeline Banda, madeline.banda@aut.ac.nz, telephone: 09 921 9999, extension 8044.

Whom do I or my child contact for further information about this research?

Please contact, Travis McMaster, t.mcmaster@aut.ac.nz, mobile 022 624 8050.

Student Researcher Contact Details:

César Meylan, cesar.meylan@aut.ac.nz, mobile 021 0255 0953

Project Supervisor Contact Details:

Dr John Cronin, john.cronin@aut.ac.nz, telephone: 09 921 9999, extension 7523.

Approved by the Auckland University of Technology Ethics Committee on: 2nd July 2010,
AUTEC Reference number 10/74

Parents and Legal Guardians Information Sheet

Date Information Sheet Produced:

6th June 2010

Project Title

Coordination-agility vs. strength-power training in prepubescent athletes

An Invitation

I, César Meylan, am a Doctoral candidate at the AUT University in Auckland, as well as a Fitness Football coordinator for New Zealand Football and a coach in the Long Term Athlete Development programme at the Milliennium Institute of Sport and Health,

I would like to invite your child to participate in a research studying the effect of a coordination-agility training, a strength-power training programme or regular activity on the jump, speed and agility abilities in prepubescent athletes. Your child will be assigned to one of the two groups who perform extra training. His/her participation is entirely voluntary and whether or not he/she chooses to participate will neither advantage nor disadvantage him/her in relation to his/her training. Please understand that your son/daughter may withdraw at any time without any adverse consequences.

Travis McMaster, a doctoral student in the School of Sport and Recreation at AUT University, will be your point of contact if you have any further questions regarding this research. His contact details are described later in this document.

What is the purpose of this research?

The purpose of this project is to examine the effect of a coordination-agility training, a strength-power training programme or regular activity on the jump, speed and agility abilities in prepubescent athletes.

How was my child chosen for this invitation?

Your child is a young athlete that is regularly physically active and engaged in sport.

What will happen in this research?

Your son/daughter will be attending a testing session before and after a eight week training period. During these testing sessions anthropometric measurements (skinfolds, girth, breath, height, sitting height, weight, height of second sacrum vertebrae) will be taken first followed by physical performance tests. Performance tests will include a vertical countermovement jump, a horizontal countermovement jump, 30 meter sprint and agility tests. Prior to testing, your child will undertake a 10-minute standardized warm-up consisting of five minutes of jogging followed by a series of dynamic movements (e.g. lunges and skipping). During the eight week training period, the experimental groups (LTAD

athletes) will follow a eight week training programme using coordination-agility or strength-power exercises. The control group will not follow any structured training. Your child will be part of one of the two training groups. Training will be progressive loaded over the 8 weeks. All training intensity, load, volume and duration will follow the guidelines for youth resistance training and will match the young athletes' readiness for this type of training. Sessions will last for 20 minutes three times per week and will not overload the system more than usual as the training programme will be part of the regular hour training usually conducted in the LTAD programme

What are the discomforts and risks?

The anticipated discomforts and risks from participating in this testing differ very little to the regular physical activity engaged in at LTAD or school. The main discomfort your child may experience during some of the testing and training is a mild soreness sensation in his/her legs along with some heavy or labored breathing. Both of these responses are normal and triggered by the onset of any exercise. As with training, the degree to which this occurs varies depending on your child's level of exertion, current fitness and personal tolerance to exercising. These symptoms should dissipate quite quickly during the recovery period assigned after each test.

The other possible discomfort is delayed onset of muscle soreness (DOMS) the following or subsequent two days after testing/training. However, your child is less likely to get DOMS after testing as your son/daughter will have enough time to recover in between trials. Any muscle soreness should dissipate within 3 to 5 days.

Participants will be asked to wear shorts and a singlet for the anthropometry measurements which can create a small discomfort. However, you are welcome to be in the room to reassure the child. In addition, all anthropometric measurement will be made following the guidelines outlined by the International Society for the Advanced of Kinoanthropometry.

All training intensity, load, volume and duration will follow the guidelines for youth resistance training and will match the young athletes' readiness to this type of training. Therefore your child should not experience more discomfort that in regular sports he/she is practicing.

How will these discomforts and risks be alleviated?

Your child will have the opportunity to familiarize him/herself with the testing procedures.

To reduce discomforts and risks from testing, your son/daughter will be asked to physically prepare him/herself prior to the first test by undertaking a warm up under supervision. It will also help if he/she also stays warm and drinks fluids throughout the testing and training sessions.

Immediately after each test, he/she will be asked to rest for 30 to 60 seconds to keep blood circulating and to assist with the breakdown of possible lactic acid – light walking is better than standing still or lying down. If your child needs more time to prepare or recover between tests, he/she should notify the researcher, as we are interested in measuring his/her best performance. If your child does not feel able to complete the test requested, he/she should notify the researcher immediately and the testing will be terminated.

The tester of each station cannot be gender specific. However, all testers will all the sensitivity to assess opposite gender and have done these tests with both genders in the past for the LTAD programme. Furthermore all assessments take place in environments where there are more than the assessor and the subject i.e. minimum of 4 subjects.

Finally, your son/daughter should notify the researcher, if he/she has a current injury or have had an injury within the last four months that might affect his/her performance, or that might be worsened or aggravated by the required activity. For example, a current knee injury would exclude him/her from the running as well as a current arm or shoulder injury. If discomfort occurs during a sprint bout, your child will be recommended to withdraw from testing on that occasion.

What are the benefits?

By participating in this study, your child may improve his/her athletic abilities. The project will help assess the efficiency of different training methods and ensure that best methods of practice are applied in youth sports. These methods can then be implemented to a wider group of athletes.

What compensation is available for injury or negligence?

In the unlikely event of a physical injury as a result of your child's 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 child's privacy be protected?

The identity and results of each participant will be kept confidential. Only the researcher (César Meylan) and the primary supervisor (Prof. John Cronin) will analyze your results. Individual results are de-identified and usually pooled and presented as averages when presented in media.

What are the costs of participating in this research?

There are no costs to participation, apart from scheduling your and your child's time to be available for testing.

What opportunity does my child have to consider this invitation?

After he/she has read through this form, you and your child will have plenty of opportunity to ask any questions you would like about the study up to the first testing occasion. The initial testing session is scheduled to commence May 2010. The final testing day will be scheduled nine weeks after the initial testing and the eight week programme will occur between the initial and final testing.

After you and your child's concerns have been satisfied, your son/daughter will need to decide whether or not he/she would like to participate in the research. As a parent, you can be present at all testing and training sessions, if you and/or your child wish.

How do my child agree to participate in this research?

If your child would like to participate in this research, you need to sign the attached *Consent Form*, while your child needs to fill in and sign the attached *Assent Form* and return it to Travis McMaster prior to participating in any of the tests for each project stage. Please note that your child is not able to participate in this research if you and your child have not filled out and signed the forms.

If your son/daughter does not wish to participate in this research, he/she should notify the researcher also. Please understand that your child may withdraw at any time without any adverse consequences.

Will my child receive feedback on the results of this research?

Yes, he/she can receive a summary of his/her individual results once the information is ready for distribution (around end July 2010). Please check the appropriate box on the *Consent Form* if you would like this information.

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

Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor, Dr John Cronin, john.cronin@aut.ac.nz, telephone: 09 921 9999, extension 7523.

Concerns regarding the conduct of the research should be notified to the Executive Secretary, AUTEC, Madeline Banda, madeline.banda@aut.ac.nz, telephone: 09 921 9999, extension 8044.

Whom do I or my child contact for further information about this research?

Please contact, Travis McMaster, t.mcmaster@aut.ac.nz, mobile 022 624 8050.

Student Researcher Contact Details:

César Meylan, cesar.meylan@aut.ac.nz, mobile 021 0255 0953

Project Supervisor Contact Details:

Dr John Cronin, john.cronin@aut.ac.nz, telephone: 09 921 9999, extension 7523.

Approved by the Auckland University of Technology Ethics Committee on: 3rd June 2010
AUTEC Reference number 10/55

Parents and Legal Guardians Information Sheet

Date Information Sheet Produced:

19th July 2011

Project Title

The effect of high-load low-velocity strength training on power and sprint performance in children of different maturity status

An Invitation

I, César Meylan, am a Doctoral candidate at the AUT University in Auckland, as well as a Fitness Football coordinator for New Zealand Football and Strength and Conditioners of the Football Ferns,

I would like to invite your child to participate in a research studying the effect of resistance training or regular activity on the strength, power, jump and speed abilities in athletes of different maturity status. Your son will be assigned to one of the two groups. His participation is entirely voluntary and whether or not he chooses to participate will neither advantage nor disadvantage him in relation to any current team involvement at school. Please understand that your son may withdraw at any time without any adverse consequences.

What is the purpose of this research?

The purpose of this project is to examine the effect of resistance training or regular activity on the strength, power, jump and speed abilities in athletes of different maturity status.

How was my child chosen for this invitation?

Your child is a young athlete that is regularly physically active and engaged in sport.

What will happen in this research?

Your son will be attending a testing session before and after a eight week training period. During these testing sessions anthropometric measurements (skinfolds, height, sitting height, weight) will be taken followed by physical performance tests. The first performance tests will include explosive supine squats at five different relative loads to body weight (BW) on the supine squat machine: -20%BW, BW, 20%BW, 40%BW and 60%BW. In the second day of testing for both pre and post training, three trials of vertical and horizontal countermovement jumps and three trials of a 30 m sprint will be performed. Prior to testing, your child will undertake a 15-minute standardized warm-up consisting of movements on the supine squat machine. Following the warm-up, the testing session on the supine squat machine will be 45 min and the session including the jumping and sprinting performance will be 30 min. During the eight week training period, the experimental group will follow a eight week resistance training program. The
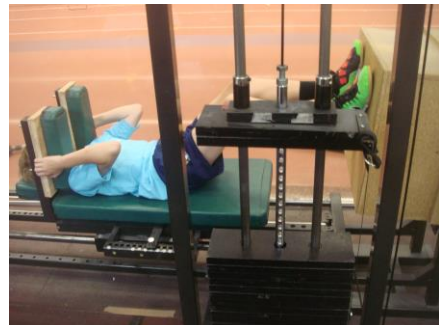
control group will not follow any structured training. Your child will randomly be assigned to one of the two groups. Training will be progressively loaded over the 8 weeks. All training intensity, load, volume and duration will follow the guidelines for youth resistance training and will match the young athletes' readiness for this type of training. Sessions will last for 45 minutes two times per week prior to or after school and will not overload the system excessively.

What are the discomforts and risks?

The anticipated discomforts and risks from participating in this testing differ very little to the regular physical activity engaged in clubs or school. The main discomfort your child may experience during some of the testing and training is a mild soreness sensation in his legs along with some heavy or labored breathing. Both of these responses are normal and triggered by the onset of any exercise. As with training, the degree to which this occurs varies depending on your child's level of exertion, current fitness and personal tolerance to exercising. These symptoms should dissipate quite quickly during the recovery period assigned after each test.

The other possible discomfort is delayed onset of muscle soreness (DOMS) the following or subsequent two days after testing/training. However, your child is less likely to get DOMS after testing as your son will have enough time to recover in between trials. Any muscle soreness should dissipate within 3 to 5 days.

Participants will be asked to wear shorts and a singlet for the anthropometry measurements which can create a small discomfort. However, you are welcome to be in the room to reassure the child. In addition, all anthropometric measurement will be made following the guidelines outlined by the International Society for the Advancement of Kinoanthropometry.

All training intensity, load, volume and duration will follow the guidelines for youth resistance training and will match the young athletes' readiness to this type of training. Therefore your child should not experience more discomfort that in regular sports he is practicing.

How will these discomforts and risks be alleviated?

Your child will have the opportunity to familiarize himself with the testing procedures.

To reduce discomforts and risks from testing, your son will be asked to physically prepare himself prior to the first test by undertaking a supervised warm up. It will also help if he also stays warm and drinks fluids throughout the testing and training sessions.

Immediately after each test, he will be asked to rest for 30 to 60 seconds to keep blood circulating and to assist with the breakdown of possible lactic acid – light walking is better than standing still or lying down. If your child needs more time to prepare or recover between tests, he should notify the researcher, as we are interested in measuring his best performance. If your child does not feel able to complete the test requested, he/she should notify the researcher immediately and the testing will be terminated.

Finally, your son should notify the researcher, if he has a current injury or has had an injury within the last four months that might affect his performance, or that might be aggravated by the required activity. For example, a current knee injury would exclude him from the study. If discomfort occurs during exercising, your child will be recommended to withdraw from testing on that occasion.

What are the benefits?

By participating in this study, your child may improve his athletic abilities. He will learn to train correctly and his movement competency will be progressed over the 8 week training cycle. The project will help assess the efficiency of different training methods and ensure that best methods of practice are applied in youth sports. These methods can then be implemented to a wider group of athletes. Also the fitness results are available on request should you or your son be interested in viewing the results.

What compensation is available for injury or negligence?

In the unlikely event of a physical injury as a result of your child's 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 child's privacy be protected?

The identity and results of each participant will be kept confidential. Only the researcher (César Meylan) and the primary supervisor (Prof. John Cronin) will analyze your results. Individual results are de-identified and usually pooled and presented as averages when presented in media.

What are the costs of participating in this research?

There are no costs to participation, apart from scheduling your and your child's time to be available for testing.

What opportunity does my child have to consider this invitation?

After he has read through this form, you and your child will have plenty of opportunity to ask any questions you would like about the study up to the first testing occasion. The initial testing session is scheduled to commence 1st August 2011. The final testing day will be scheduled eight weeks after the initial testing and the eight week programme will occur between the initial and final testing.

After you and your child's concerns have been satisfied, your son will need to decide whether or not he would like to participate in the research. As a parent, you can be present at all testing and training sessions, if you and/or your child wish.

How do my child agree to participate in this research?

If your child would like to participate in this research, you need to sign the attached *Consent Form*, while your child needs to fill in and sign the attached *Assent Form* and return it to César Meylan prior to participating in any of the tests for each project stage. Please note that your child is not able to participate in this research if you and your child have not filled out and signed the forms.

If your son does not wish to participate in this research, he should notify the researcher also. Please understand that your child may withdraw at any time without any adverse consequences.

Will my child receive feedback on the results of this research?

Yes, he can receive a summary of his individual results once the information is ready for distribution (around end of October 2011). Please check the appropriate box on the *Consent Form* if you would like this information.

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

Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor, Dr John Cronin, john.cronin@aut.ac.nz, telephone: 09 921 9999, extension 7523.

Concerns regarding the conduct of the research should be notified to the Executive Secretary, AUTEC, Madeline Banda, madeline.banda@aut.ac.nz, telephone: 09 921 9999, extension 8044.

Whom do I or my child contact for further information about this research?

Please contact, César Meylan, cesar.meylan@aut.ac.nz, mobile 022 699 7461.

Student Researcher Contact Details:

César Meylan, cesar.meylan@aut.ac.nz, mobile 022 699 7461

Project Supervisor Contact Details:

Dr John Cronin, john.cronin@aut.ac.nz, telephone: 09 921 9999, extension 7523.

Approved by the Auckland University of Technology Ethics Committee on 7th of June 2011, AUTEC Reference number 11/122

Appendix 4: Consent form

# Parents and Legal Guardians # Consent Form	**AUT** UNIVERSITY TE WĀNANGA ARONUI O TAMAKI MAKAU RAU

Project title: The stability of vertical and horizontal jump measures in children of different age

Project Supervisor: Dr John Cronin

Researcher: César Meylan

○   I have read and understood the information provided about this research project in the Information Sheet dated dd mmmm yyyy.

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

○   I understand that my child may withdraw him/herself or any information that he/she has provided for this project at any time prior to completion of data collection, without being disadvantaged in any way.

○   My son/daughter does not suffer from heart disease, high blood pressure, any respiratory condition (mild asthma excluded), any illness or injury that impairs his/her physical performance (or that might be aggravated by the tasks requested), or any infection

○   I agree to let my child take part in this research.

○   I wish to receive a copy of my child's individual results from this research project (please tick one):
Yes○   No○

○   I would like to be invited to group information session to hear about the main findings from this research project (please tick one):
Yes○   No○

Participant's name: ....……………………………………………………

Participant's guardians signature: ....……………………………………………

Participant's guardians name: ....…………………………………………

Participant's Contact Details (if appropriate):

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……………………………………………………………………………………..

Email:…….………………………………………………………………………..

Date:

Approved by the Auckland University of Technology Ethics Committee on 6th July 2010, AUTEC Reference number 10/75

Note: The Participant should retain a copy of this form

Parents and Legal Guardians Consent Form

Project title: The reliability and validity of force-velocity-power profiling in males of different maturity status

Project Supervisor: Dr John Cronin

Researcher: César Meylan

○ I have read and understood the information provided about this research project in the Information Sheet dated dd mmmm yyyy.

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

○ I understand that my child may withdraw him/herself or any information that he/she has provided for this project at any time prior to completion of data collection, without being disadvantaged in any way.

○ My son/daughter does not suffer from heart disease, high blood pressure, any respiratory condition (mild asthma excluded), any illness or injury that impairs his/her physical performance (or that might be aggravated by the tasks requested), or any infection

○ I agree to let my child take part in this research.

○ I wish to receive a copy of my child's individual results from this research project (please tick one):
Yes○   No○

○ I would like to be invited to group information session to hear about the main findings from this research project (please tick one):
Yes○   No○

Participant's name: ....…………………………………………………………

Participant's guardians signature: ....…………………………………………………

Participant's guardians name: ....…………………………………………………

Participant's Contact Details (if appropriate):

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Email:…………………………………………………………………………..

Date:

Approved by the Auckland University of Technology Ethics Committee on 2nd July 2010, AUTEC Reference number 10/74

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

Consent Form

AUT UNIVERSITY
TE WĀNANGA ARONUI O TAMAKI MAKAU RAU

Project title: Coordination-agility vs. strength-power training in prepubescent athletes

Project Supervisor: Dr John Cronin

Researcher: César Meylan

○ I have read and understood the information provided about this research project in the Information Sheet dated dd mmmm yyyy.

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

○ I understand that my child may withdraw him/herself or any information that he/she has provided for this project at any time prior to completion of data collection, without being disadvantaged in any way.

○ My son/daughter does not suffer from heart disease, high blood pressure, any respiratory condition (mild asthma excluded), any illness or injury that impairs his/her physical performance (or that might be aggravated by the tasks requested), or any infection

○ I understand that my child will be assigned to one of the two groups, either the control group or the training group.

○ I wish to receive a copy of my child's individual results from this research project (please tick one):
Yes○   No○

○ I would like to be invited to group information session to hear about the main findings from this research project (please tick one):

Yes○   No○

Participant's name: ....…………………………………………………

Participant's guardians signature: ....…………………………………………………

Participant's guardians name: ....…………………………………………

Participant's Contact Details (if appropriate):

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Email:…………………………………………………………………………..

Date:

Approved by the Auckland University of Technology Ethics Committee on 3rd June 2010, AUTEC Reference number 10/55

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

<table>
<tr><td></td><td># Consent Form</td><td>

AUT
UNIVERSITY
TE WĀNANGA ARONUI O TAMAKI MAKAU RAU
</td></tr>
</table>

Project title: The effect of high-load low-velocity strength training on power and sprint performance in children of different maturity status

Project Supervisor: Dr John Cronin

Researcher: César Meylan

○ I have read and understood the information provided about this research project in the Information Sheet dated dd mmmm yyyy.

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

○ I understand that my child may withdraw him/herself or any information that he/she has provided for this project at any time prior to completion of data collection, without being disadvantaged in any way.

○ My son does not suffer from heart disease, high blood pressure, any respiratory condition (mild asthma excluded), any illness or injury that impairs his/her physical performance (or that might be aggravated by the tasks requested), or any infection

○ I understand that my child will be assigned to one of the two groups, either the control group or the training group.

○ I wish to receive a copy of my child's individual results from this research project (please tick one):
Yes○ No○

○ I would like to be invited to group information session to hear about the main findings from this research project (please tick one):

Yes○ No○

Participant's name: ....……………………………………………………

Participant's guardians signature: ....……………………………………………

Participant's guardians name: ....………………………………………………

Participant's Contact Details (if appropriate):

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……………………………………………………………………………..

……………………………………………………………………………..

Email:……..……………………………………………………………………..

Date:

Approved by the Auckland University of Technology Ethics Committee on 7[h] July 2011, AUTEC Reference number 11/122

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

Appendix 5: Assent form

Assent Form

AUT
UNIVERSITY
TE WĀNANGA ARONUI O TAMAKI MAKAU RAU

Project title: The stability of vertical and horizontal jump measures in children of different age

Project Supervisor: Dr John Cronin

Researcher: César Meylan

Please tick the circles below if you understand and agree with the different points and sign the sheet

○ I have read and understood the sheet telling me what will happen in this study and why it is important.

○ I have been able to ask questions and to have them answered.

○ I understand that notes will be taken during the testing.

○ I understand that while the information is being collected, I can stop being part of this study whenever I want and that it is perfectly ok for me to do this.

○ If I stop being part of the study, I understand that all information about me, including the recordings or any part of them that include me, will be destroyed.

○ I agree to take part in this research.

Participant's signature: ....………………………………………………………

Participant's name: ....………………………………………………………

Participant Contact Details (if appropriate):

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Date:

Approved by the Auckland University of Technology Ethics Committee on 6th July 2010. AUTEC Reference number 10/75

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

Assent Form

Project title: The reliability and validity of force-velocity-power profiling in males of different maturity status

Project Supervisor: Dr John Cronin

Researcher: César Meylan

Please tick the circles below if you understand and agree with the different points and sign the sheet

○   I have read and understood the sheet telling me what will happen in this study and why it is important.

○   I have been able to ask questions and have them answered.

○   I understand that notes will be taken during the testing.

○   I understand that while the information is being collected, I can stop being part of this study whenever I want and that it is perfectly ok for me to do this.

○   If I stop being part of the study, I understand that all information about me, including the recordings or any part of them that include me, will be destroyed.

○   I agree to take part in this research.

Participant's signature: ....……………………………………………………

Participant's name: ....……………………………………………………

Participant Contact Details (if appropriate):

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Date:

Approved by the Auckland University of Technology Ethics Committee on 2nd July 2010, AUTEC Reference number 10/74

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

Assent Form

Project title: The effect of high load low velocity training on power development in different maturity group

Project Supervisor: Dr John Cronin

Researcher: César Meylan

○   I have read and understood the sheet telling me what will happen in this study and why it is important.

○   I have been able to ask questions and to have them answered.

○   I understand that notes will be taken during the testing.

○   I understand that while the information is being collected, I can stop being part of this study whenever I want and that it is perfectly ok for me to do this.

○   If I stop being part of the study, I understand that all information about me, including the recordings or any part of them that include me, will be destroyed.

○   I agree to take part in this research.

Participant's signature: ....……………………………………………………

Participant's name: ....……………………………………………………

Participant Contact Details (if appropriate):

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Date:

Approved by the Auckland University of Technology Ethics Committee on 3rd June 2010 AUTEC Reference number 10/55

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

Assent Form

Project title: The effect of strength training on muscle strength, jump and sprint performance in children 12-15 years of age.

Project Supervisor: Dr John Cronin

Researcher: César Meylan

○ I have read and understood the sheet telling me what will happen in this study and why it is important.

○ I have been able to ask questions and to have them answered.

○ I understand that notes will be taken during the testing.

○ I understand that while the information is being collected, I can stop being part of this study whenever I want and that it is perfectly ok for me to do this.

○ If I stop being part of the study, I understand that all information about me, including the recordings or any part of them that include me, will be destroyed.

○ I agree to take part in this research.

Participant's signature: ....……………………………………………………

Participant's name: ....……………………………………………………

Participant Contact Details (if appropriate):

……………………………………………………………………………………..

……………………………………………………………………………………..

……………………………………………………………………………………..

Email:………………………………………………………………………………………..

Date:

Approved by the Auckland University of Technology Ethics Committee on 7t^h June, 2011, AUTEC Reference number 11/122

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

Appendix 6: Questionnaire

Research Project: Coordination-agility vs. strength-power training in prepubescent athletes

Questionnaire

Dear Parents and athletes,

We would appreciate if you could answer to the best of your abilities the following questions and return this questionnaire before the end of the study.

1. Parents height (cm):

- Father: .... cm

- Mother: .... cm

2. How many hours per week your child is being involved in different sports during the current school term. The hours detailed must be the ones involved in a structured environment such as school, club or LTAD. Include the hours of practice and competition of a sport under the same topic. Please use the following table to fill in the log of the hours/week of different activities. If there is a sport starting or finishing during the term, please spread the hours over the term. The first table is an example. Please use second table for your child.

Example

Name: Cesar Meylan	
Sports	**Hours/week**
LTAD	3
Football (club) (Game + 2 practices)	5
Resistance training	3
TOTAL	11

Name:	
Sports	Hours/week
TOTAL	

Appendix 7: Board of Trustee letter

César Meylan

2A Rossmore Terrace

Murrays bay

North Shore City, 0630

Auckland

Email: cesar.meylan@aut.ac.nz

Phone: 021 0255 0953

Dear Sir/Madam,

I am a Doctoral candidate at the AUT University in Auckland, as well as a Fitness Football coordinator for New Zealand Football and a coach in the Long Term Athlete Development programme at the Millennium Institute of Sport and Health. My field of research is the development of leg strength and power during youth. Currently, I am seeking young athletes to participate in my study entitled: "Coordination-agility vs strength-power training in prepubescent athletes". The purpose of this project is to examine the effect of coordination-agility training, strength-power training programme or regular activity on the jump, speed and agility abilities in prepubescent athletes.

Briefly, participants will be attending a testing session before and after a eight week training period. During these testing sessions anthropometric measurements (skinfolds, girth, breath, height, sitting height, weight, height of second sacrum vertebrae) will be taken followed by physical performance tests. Performance tests will include a vertical countermovement jump, a horizontal countermovement jump, 30 meter sprint and agility tests. Prior to testing, the participants will undertake a 10-minute standardized warm-up consisting of five minutes of jogging followed by a series of dynamic movements (e.g. lunges and skipping). During the eight week training period, the experimental groups will follow an eight week training programme using coordination-agility or strength-power exercises and the control group will follow their regular activity.

This letter is requesting permission to recruit participants from your school/club. The participation is entirely voluntary and whether or not the child chooses to participate will neither advantage nor disadvantage him/her in relation to his/her training. Please understand that participants may withdraw at any time without any adverse consequences. The participants recruited from your school/club will be assigned to the control group (i.e. regular activity) and therefore will not follow any extra training. Their time requirement will solely be two testing sessions of 1.5 hours, eight weeks apart. The testing will not involve greater risk of injury than regular physical activity. Parents or legal guardian and participants will receive an information letter and written consent will be collected. The results will remain confidential and personal reports can be generated if the participants/parents/legal guardians are interested.

I would really appreciate your permission in enabling this research to progress. If you have further questions please do not hesitate to contact me.

Yours Sincerely,

César Meylan

César Meylan

92A Shakespear Road

Milford

Auckland, 0620

Email: cesar.meylan@aut.ac.nz

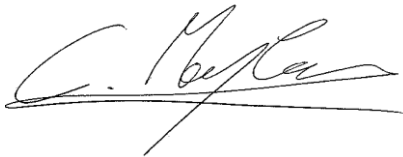Phone: 022 699 7461

10th July, 2011

Dear Sir/Madam,

I am a Doctoral candidate at AUT University in Auckland, as well as a Fitness Football coordinator for New Zealand Football and the Strength and Conditioner of the National Women Team. My field of research is the development of leg strength and power during youth. Currently, I am seeking young athletes to participate in my study entitled: "The effect of high-load low-velocity strength training on power and sprint performance in children of different maturity status". The purpose of this project is to examine the effect of weight training programme or regular activity on the strength, power, jump, and speed abilities in athletes of different maturity status.

Briefly, participants will be attending two testing session before and after a eight week training period. During these testing sessions anthropometric measurements (skinfolds, height, sitting height, weight) will be taken followed by physical performance tests. Physical assessment will include a ballistic (jump) movement on a supine squat machine at five different relative loads to body weight (BW) in a randomised order: -20%BW, BW, 20%BW, 40%BW and 60%BW. In addition, three trials of vertical and horizontal countermovement jumps and three trials of a 30 m sprint will be performed. Athlete's parents will be required to provide the child's parental biological height. Prior to testing, the participants will undertake a 15-minute standardized warm-up. During the eight week training period, the experimental groups will follow an eight week training programme using weight exercises and the control group will follow their regular activity.

This letter is requesting permission to recruit participants from your school. Please understand that participants may withdraw at any time without any adverse consequences. The participants recruited from your school will be assigned to the training or control group (i.e. regular activity). Both testing and training will not involve greater risk of injury than regular physical activity. Parents or legal guardians and participants will receive an information letter and written consent will be collected. The results will remain confidential and personal reports can be generated if the participants/parents/legal guardians are interested.

I would really appreciate your permission in enabling this research to progress. If you have further questions please do not hesitate to contact me.

Yours Sincerely,

César Meylan

Appendix 8: Abstracts

Chapter 2

The purpose of this paper is to provide a review around talent identification (TID) in soccer using physiological and technical testing procedures, and to summarise the issues associated with this process. The current research in soccer TID, amongst other sports, demonstrates a systematic bias in selection towards players born early in the year (i.e. relative age effect) and early maturers. From the studies investigating the physiological (e.g. power) and technical (e.g. dribbling) characteristics of players of different maturity status, early maturers had the tendency to perform better in these tests and therefore were likely to be more influential on the game and be recognised as more talented. When considering the current level of play and future success, elite youth and future professional players scored better in physiological and technical testing than recreational youth and future non-professional players, independently of maturity status. However, these testing procedures were not sensitive enough to distinguish youth elite from sub-elite or future national team from professional club players. Collectively, these studies demonstrated the need to use estimates of maturity status and subsequent appropriate analysis of data obtained from physiological and technical testing. When maturity is taken into account, these testing procedures can provide an indication of responsiveness to training load in youth players and an evaluation of potential to become a successful soccer player. However, these testing procedures should not be used as a marker of selection before full maturity is attained and should be part of a multidimensional approach of talent identification considering the importance of other facets of the game at the highest level (e.g. perceptive-cognitive skills).

Power is thought as an essential physical characteristic in soccer but no systematic and evidence-based model exists to develop this attribute in youth. Both the player's pathway and natural power development were discussed and integrated as conditioning factors to the model, where the player's pathway influenced training integration, block duration, and session length and frequency, while the natural power development dictated training emphasis, mode, intensity and volume. Furthermore, a systematic analysis of training studies that investigated the training of power in youth soccer players was conducted to determine current best practice and limitations. An initial phase concentrating on movement competency and velocity was recommended prior to puberty, before an emphasis on force production during mid-puberty (13-15 y). Once the players enter late puberty (>16 y), maximal strength and power training should be implemented. The number of power training sessions in a block, exercise progression and loading parameters should be viewed as key factors of the training design to enhance movement competency and optimise training adaptations. The implementation of a model will ensure optimal integration of power training and its constituent parts (force and velocity) with clear training emphases throughout the developmental stages of a player.

The purpose of this study was to determine the reliability of eccentric (ECC) and concentric (CON) kinematic and kinetic variables thought critical to jump performance during bilateral vertical (VCMJ) and horizontal (HCMJ) countermovement jumps across children of different maturity status. Forty-two athletic male and females between 9 and 16 years of age were divided into three maturity groups according to peak height velocity (PHV) offset (Post-PHV, At-PHV and Pre-PHV) and percent of predicted adult stature. All subjects performed three VCMJ and HCMJ trials and the kinematics and kinetics of these jumps were measured via a force plate over three testing sessions. In both jumps, vertical CON mean and peak power as well as jump height or distance were the most reliable measures across all groups (Change in the mean - CM = -5.4% to 6.2%; Coefficient of variation - CV = 2.1% to 9.4%; Intraclass coefficient – ICC = 0.82 to 0.98), while vertical ECC mean power was the only ECC variable with acceptable reliability for both jumps (CM = -0.7% to 10.1%; CV = 5.2% to 15.6%; ICC = 0.74 to 0.97). A less mature state was "likely" to "very likely" to reduce the reliability of the HCMJ ECC kinetics and kinematics. These findings suggested that movement variability is associated with the ECC phase of CMJs, especially in Pre-PHV during the HCMJ. Vertical CON mean and peak power and ECC mean power were deemed reliable and appropriate to be used in children as indicators of jump and stretch-shortening cycle performance.

The purpose of this study was to quantify the inter-session reliability of force-velocity-power profiling and estimated maximal strength in youth. Thirty-six males (11 to 15 y) performed a ballistic supine leg press test at five randomised loads (80, 100, 120, 140, 160% body mass) on three separate occasions. Peak and mean force, power, velocity and peak displacement were collected with a linear position transducer attached to the weight stack. Mean values at each load were used to calculate different regression lines and estimate maximal strength, force, velocity and power. All variables were found reliable (change in the mean - CM = -1 to 14%; coefficient of variation - CV = 3-18%; intraclass correlation coefficient - ICC = 0.74-0.99) but were likely to benefit from a familiarisation, apart from the unreliable maximal force/velocity ratio (CM =0-3%; CV = 23-25%; ICC = 0.35-0.54) and load at maximal power (CM = -1 to 2%; CV = 10-13%; ICC = 0.26-0.61). Isoinertial force-velocity-power profiling and maximal strength in youth can be assessed after a familiarization session. Such profiling may provide valuable insight into neuromuscular capabilities during growth and maturation and may be used to monitor specific training adaptations.

The purpose of this study was to examine sex-related differences in explosive actions during late childhood, while accounting for body size and maturity, and determine the predictive model responsible for performance. Sixty-eight boys (11.0 ± 1.1 y) and 45 girls (11.3 ± 0.9 y) performed a vertical and horizontal jump, 30 m sprint and change of direction (COD) time trial. Post-allometric analysis a common sex scaling factor of body mass was used for vertical (b = 1.02) and horizontal (b = 0.97) power. No significant sex difference in relative leg power was found before and after controlling for maturity status. Gender differences in 10 m, the Zigzag section and flying 10 m of the COD task were found significant once adjusted for maturity (P < 0.05). However, boys performed better than girls in 20 and 30 m sprint, and the COD time trial regardless of maturity status (P < 0.05). Reduced endomorphy in boys was the best predictor of explosive actions (R^2 = 7-22%), while female performance was best explained by mass and maturity status (R^2 = 15-19%). Jump power specific allometric scaling factors need to be determined to account for body size. A training emphasis on sprinting and COD at a younger age in girls compared to boys is recommended because of their earlier onset of puberty and reduced natural ability in these tasks. Somatotype, age, maturity and body mass should be monitored during the development of youth athletes to better understand explosive performance.

Adjustment for body mass and maturation of strength, power and velocity measures of young athletes is important for talent development. Seventy-four youth male athletes performed a ballistic leg press test at five loads relative to body mass. The data were analyzed in maturity groups based on years from peak height velocity: -2.5 to -0.9 y (n = 29); -1.0 to 0.4 y (n = 28); and 0.5 to 2.0 y (n = 16). Allometric scaling factors representing percent difference in performance per percent difference in body mass were derived by linear regression of log-transformed variables, which also permitted adjustment of performance for body mass. Standardized differences between groups were assessed via magnitude-based inference. Strength and power measures showed a greater dependency on body mass than velocity-related variables (scaling factors of 0.56 to 0.85 vs 0.42 to 0.14 %/%), but even after adjustment for body mass most differences in strength and power were substantial (7% to 44%). In conclusion, increases in strength and power with maturation are due only partly to increases in body mass. Such increases, along with appropriate adjustment for body mass, need to be taken into account when comparing performance of maturing athletes.

Understanding the contribution of neuromuscular capabilities to sprint performance can guide training. In this study we assessed the contribution of 1RM leg-press strength and jump peak power to 20-m sprint time in young athletes in three maturity groups based on age relative to predicted age of peak height velocity (PHV): Pre (-2.5 to -1.0 y; n=25), Mid (-1.0 to 0.5 y; n=26) and Post (0.5 to 2.0 y; n=15). Allometric scaling factors, representing percent difference in 20-m time per percent difference in strength and peak power, were derived by linear regression and were similar in the three maturity groups (-0.16 %/% and -0.20 %/% for strength and peak power respectively). The moderate increase in sprint performance Pre to Mid PHV (5.7%) reduced to small (1.9%) and trivial but unclear (0.9%) magnitudes after adjustment for 1RM and peak power, while the moderate increase Mid to Post PHV (4.6%) were still moderate (3.4% and 3.0%) after adjustment. Thus percent differences in strength or power explain most of the maturity-related improvements in sprint performance before PHV age but only some improvements after PHV age. Factors additional to strength and power should be identified and monitored for development of speed in athletes during puberty.

To investigate how maturity status modifies effects of strength training and detraining on performance, we subjected 33 young males to eight weeks of strength training twice per week followed by eight weeks without training. Changes in performance tests were analyzed in three maturity groups based on years from/to age of predicted peak height velocity (PHV): Pre PHV (-1.7 ± 0.4 y; n=10), Mid PHV (-0.2 ± 0.4 y; n=11) and Post PHV (1.0 ± 0.4 y; n=12). Mean training effects on 1-RM strength (3.6 to 10%), maximum explosive power (11 to 20 %), jump length (6.5 to 7.4 %) and sprint times (-2.1 to -4.7 %) ranged from small to large, with generally greater changes in Mid- and Post-PHV groups. Changes in force-velocity relationships reflected generally greater increases in strength at faster velocities. In the detraining period the Pre-PHV group showed greatest loss of strength and power, the post-PHV group showed some loss of sprint performance, but all groups maintained or improved jump length. Strength training was thus generally less effective before the growth spurt. Maintenance programs are needed for most aspects of explosive performance following strength training before the growth spurt and for sprint speed after the growth spurt.